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Image Fusion using Spatial Frequency Discrete Wavelet Transform and TYPE-2 Fuzzy Logic

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***Abstract*—Image fusion is very popular topic nowadays for researchers so, it is widely used by many researches. Image fusion is used in many applications like medical fields, military applications, remote sensing. More detailed information can be obtained from a combined image. Need of storage also decrease as it generates and saves single image instead of saving two different kinds of images. Image fusion using spatial frequency discrete wavelet transform and type-2 fuzzy logic system is proposed. Image fusion is a technique, which is used to fuse or unite two or more images of different kinds into a single image. This single fused image is more explanatory than the individual images alone. The fusion process is based on pixel-based image fusion. Pixel based image fusion is most popular and it provides image fusion without relics. In this method, initially, the images are instinctively decomposed into low level sub bands and high-level sub bands by spatial frequency discrete wavelet transform. In the second step, for fusion process, Type-2 fuzzy technique is applied for low-level sub band and average fusion method is applied for high-level sub bands in order to intensify the most conspicuous features present in images. Finally, the two fused sub bands are renovated to form the final fused image by using inverse discrete wavelet transform. The performance of the proposed work is evaluated with quantitative and qualitative parameters like normalized cross correlation coefficient, peak signal to noise ratio, structural similarity index, mean absolute error, normalized root mean square error, percentage fit error. From the results observed that the proposed method provides an improvement over other primary fusion methods.**

Keywords*— *Image fusion, Spatial frequency, DWT,Type-2 fuzzy logic system, PSNR,SSIM,MAE,NCC

I. INTRODUCTION

In medical imaging and military imaging, image fusion is most extensively used in recent days. Image fusion is a technique, which is used to fuse or unite two or more images of different kinds into a single image. Images with different types, different focused regions, images taken in different times.

In the field of medical imaging, different multi-modal images such as Computed Tomography (CT), Magnetic Resonance Image (MRI), Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) are used to analyze different characteristics of human body part. These images are employed and the exposure with respect sensors to the object. CT images are taken from a cross-sectional image of the body part by using X-rays. In the human body, the presence of fat, water and other fluids in the body to detect MRI images depending upon the various radiations used. It works on the principal that certain elements oriented themselves in presence of an outer field. The function of MRI images is illustrating the response of brain to an outer stimulus. It detects changes in the blood flow. The images produced may differ with time. These images cannot give clarity picture needed for medical image treatment like clinical diagnosis, surgery, monitoring and analysis. Thus, for efficient medical image treatment, one needs a single image with different multimodal images information. This can be carried out by image fusion techniques.

In recent view, for medical imaging and military applications many fusion techniques were proposed by the researchers. These fusion techniques are classified into region, pixel and decision levels. When compared to region and decision levels, the pixel level fusion is most popular for medical image fusion. Pixel based image fusion is most popular and it provides image fusion without relics. The pixel level fusion techniques are divided into spatial fusion and transform fusion methods. The spatial fusion methods include the average method, minimum method, maximum method, contrast pyramid, principal component analysis (PCA) method, Laplacian pyramid and Gaussian pyramid method. The above methods are directly applied on the image pixels. In the resultant images the signal-to-noise ratio (SNR) can be reduce and it introduces spatial and spectral distortion in the fused image. Transform-based fusion methods are used to overcome this problem. The transform based fusion methods include decomposition of image by stationary wavelet transform (SWT), discrete wavelet transforms (DWT), lifting wavelet transform (LWT), Redundancy discrete wavelet transform (RDWT), and Dual-tree complex wavelet transform (DTDWT). The above methods have some common drawbacks such as additive noise in fused images.

A novel approach with spatial frequency DWT-type2 fuzzy logic is proposed to solve the above problems. In image processing, Fuzzy logic theory is used for soft computing technology. For unreliability problems, when compared to basic image fusion methods, fuzzy logic-based image fusion methods are easy to handle and it is used as either a feature transform operator or a decision operator for image fusion. In this proposed method, source images are instinctively decomposed into low level sub bands and high-level sub bands by spatial frequency discrete wavelet transform. In the second step, for fusion process, Type-2 fuzzy technique is applied for low-level sub band and average fusion method is applied for high-level sub bands. Finally, the two fused sub bands are reconstructed to form the final fused image by

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using inverse discrete wavelet transform. The advantages of the proposed method can be stated as, there is no need of prior information about source images, the contribution of the source image pixels is increased and also the visibility of the regions is improved.

The remaining paper is developed as follows: Section-2 elaborates the proposed method, Section-3 discusses the performance evaluation measures, Section-4 briefly describes the experimental results and performance analysis, Conclusion and future work are summarized at the end.

II. PROPOSED METHOD

Image fusion using spatial frequency discrete wavelet transform and type-2 fuzzy logic method is proposed. Spatial frequency calculates the amount of frequency contents present in the image. It determines sharpness and spectral quality of the image. The effect of SFDWT will be more absolutely in images with high frequency contents.

Spatial frequency is defined as follows. For an MXN image F with gray value $F(i,j)$ at position (i,j) is given by

Spatial frequency

$$Fs = \sqrt{F_R^2 + F_C^2}$$

Row frequency

$$F_R = \sqrt{\frac{1}{M*N}\sum_{i=0}^{M-1}\sum_{j=1}^{N-1}|F(i,j) - F(i,j-1)|^2}$$

Column frequency

$$F_C = \sqrt{\frac{1}{M*N}\sum_{j=0}^{N-1}\sum_{i=1}^{M-1}|F(i,j) - F(i-1,j)|^2}$$

Where, F represents fused image, M & N denotes the dimensions of the fused image.

The proposed method makes use of DWT to extract the spatial information contained in image A and image B. It fuses using the proposed fusion rule which is based on spatial frequency to get high-resolution images. It can be perceived that, image fusion method, the high frequency

Component of one image (image A) is replaced with that of the high frequency component of another image (image B). The detailed coefficients of image A are removed. Finally, useful information present in the detailed coefficients of image A by using spatial frequency discrete wavelet transforms method.

The proposed spatial frequency DWT-type2 fuzzy method consists of three steps: decomposition, fusion and reconstruction. The block diagram of the proposed spatial frequency of DWT-type2 fuzzy method is shown in Fig. 1.

The steps involved in the proposed method are as follows:

1. Input two images. Image (A) and Image (B).
2. Decompose both input images using spatial frequency discrete wavelet transformation.
3. Four images will be obtained; approximate sub-image, Horizontal frequency subband, Vertical frequency sub band and Diagonal frequency subband.
4. Type-2 fuzzy logic is applied for low-frequency subbands.
5. Averaging fusion rule for high-frequency subbands.
6. Two fused sub bands are reconstructed to form the final fused image by using inverse discrete wavelet transform

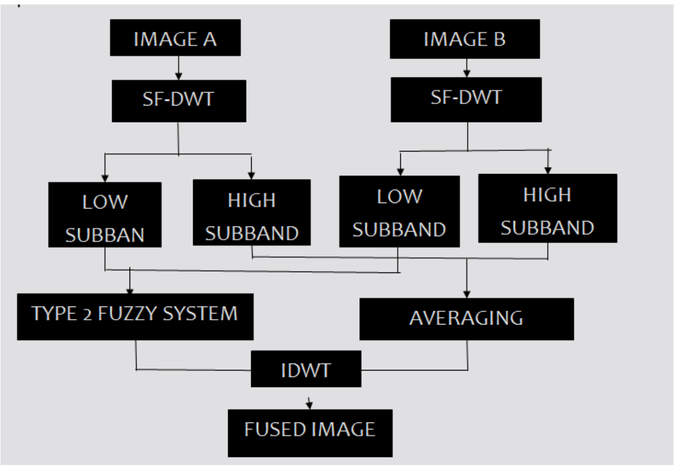

Fig. 1. Block Diagram Of Proposed Spatial Frequency DWT-Type2 Fuzzy Method

1. *Decomposition:*

In the proposed method, the input images are decomposed by a two-level spatial frequency DWT technique. In spatial frequency discrete wavelet Transformation, wavelets are discretely sampled and knowledge of both location and frequency as opposed to the Fourier transformation. In the first level of decomposition, the input images are decomposed into a low-level sub band and high-level sub bands by using spatial frequency DWT. The low-level sub band is also decomposed into another set of low-level, high-level sub bands are produced at second level. Finally, the four components of the images are the approximate sub band, Horizontal detail sub band, vertical detail sub band and diagonal detail sub band. The decompose procedure is defined as

$$[A1, H1, V1, D1] = dwt2(A)$$

$$[A2, H2, V2, D2] = dwt2(B)$$

Where A and Bare source images, *A1*, *H1*, *V1*, *D1* and *A2*, *H2*, *V2*, *D2* are decomposed coefficients of A and B images respectively. The obtained high-frequency and low-frequency subbands of the two images are fused using a fusion algorithm.

2. *Fusion:*

i. Fusion of Low-frequency Sub-images:

Fuzzy sets are used to solve the uncertainty problems. On the basis of a membership function the element in the sets is classified. These functions highly depend on intuition are not flexible and hence the uncertainty problem is not labeled properly. In order to reduce fuzziness, the membership function is limited by another fuzzy set with a membership function which forms the second level of the fuzzy technique. This definition of a membership function on a second level is termed as type-2 fuzzy logic system. To reduce the complexity involved in type-2 fuzzy logic system technique, a variable alpha (α) is chosen to define the lower and upper limits of the function.

The low-level subbands acquired after decomposition of the source images are categorized into corresponding fuzzy sets based on a defined membership function. These fuzzy sets are analyzing for the maximum fuzzy entropy which are the best suited coefficients for the fusion process of the subbands. The fuzzy entropy of the image is easily regulated the degree of fuzziness of the sub-images. Hence, the determination of the subbands to be the suitable coefficients of the image fusion frame is made by measuring the degree of fuzziness of each image.

we determine membership function on each low-level frequency sub-bands as given below.

$$F(i,j) = \frac{(F_3(i,j) - L(i,j))}{(F_3(i,j) - F_2(i,j))}$$

Where $F3(i,j)$ is the max of the approximate image, $F_2(i,j)$is the minimum frequency value of the approximate image, L is the approximate sub-bands of the images $(A1, A2)$, f is the first level fuzzy set.

After the membership function is defined and obtained, the lower and upper limits of the level-2 membership are obtained based on the variable alpha as chosen.

$$\alpha = 2;$$

$$F_{lo} = F(i,j)^{\alpha}$$

$$F_{up} = F(i,j)^{1/\alpha}$$

Where $(A1, A2)$ denotes the sub-bands, α is the chosen arbitrary value.

According to the information theory, a fuzzy set has larger fuzzy entropy and it contains more information. Hence, after determine the membership functions, entropy of these fuzzy sets are calculated based on the following formula.

$$E_n = (F_{lo} * \alpha) + (F_{up} * (1 - \alpha))$$

Based on the entropy, corresponding values of the subbands are chosen to be present in the final image.

$$A3 = \begin{cases} mean & if\ SF1 > SF2 \\ max & if\ SF1 < SF2 \\ \min & otherwise \end{cases}$$

Where SF is the spatial frequency of low frequency images and *E1*, *E2* are the entropy of the approximate subbands of the images A and B respectively.

ii. Fusion of high-frequency sub-images:

By using the averaging filter, High-frequency subbands are fused. Each detailed subbands of the image A are fused along with its corresponding detailed image B. Hence, three fused sub-images are obtained after the process.

$$H3 = AVG(H1 + H2)$$

$$V3 = AVG(V1 + V2)$$

$$D3 = AVG(D1 + D2)$$

3. *Reconstruction:*

According to the fusion algorithms, the four sub-images are fused. Inverse wavelet transformation is applied on the resultant four sub-images. Reconstruction is the inverse process of up-sampling of images. A rescaling filter is applied to the low frequency subband and wavelet filter is used for the high-frequency subbands. The reconstruction of the final image as follows.

$$F = idwt2(A3, H3, V3, D3)$$

F represents the final fused image.

III. QUALITY MEASURES

The performance of the fused image is analyzed by using subjective and objective measures. The subjective analysis relates with the visual perception. Objective analysis of the fused image is done by using various measures such as Mean Absolute Error (MSE), Peak Signal to Noise Ratio (PSNR), Normalized Cross Correlation (NCC) and Structural Similarity Index (SSIM),Normalized Root Mean Square Error(NRMSE), Percentage Fit Error(PFE). The measures are given below, Let us consider a source image $S(i,j)$and the fused image $F(i,j)$ of size M∗N.

1. *Normalized cross correlation:*

Normalized Cross Correlation (NCC) determines the degree of similarity between source image and fused image and it expressed as

$$\frac{\sum_{i=1}^{M}\sum_{j=1}^{N} F(i,j)\ S(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} F(i,j)^2}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} S(i,j)^2}}$$

The correlation coefficient range varies from [-1,1]. Negative relationship is indicated by -1 and positive relationship is indicated by +1.

2. *Peak signal to noise ratio:*

Peak Signal to Noise Ratio (PSNR) is used to determine the improvement in the quality of the fused image and it expressed as

Mean Square error is

$$\frac{1}{M * N\ \sum_{i=0}^{M-1}\sum_{j=0}^{N-1}[F(i,j) - S(i,j)]^2}$$

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Peak Signal to noise ratio is

$$10\log_{10}\left({MAX^2}/{MSE}\right)$$

A higher PSNR value specifies a better quality of the fused image.
Where *MSE* is the mean square error value of the image and *MAX* is the maximum value of an image.

3. *Structural similarity index Measure:*

Structural Similarity Index Measure (SSIM) is used to determine the similarity between the source image and fused image. The SSIM can be expressed as

$$\frac{((2\mu_F\mu_S + C1) * (2\sigma_{FS} + C2))}{((\mu_F^2 + \mu_S^2 + C1) * (\sigma_F^2 + \mu_S^2 + C2)}$$

where μFrepresents the average intensity of fused image $F(i,j)$, μS represents the average intensity of source image $S(i,j)$, σF represents the variance of fused image $F(i,j)$, σS represents the variance of source image $S(i,j)$, $\sigma^2 S$ gives the covariance of $F(i,j)$and $S(i,j)$, $\sigma 2\ F$ gives the covariance of $F(i,j)$and $S(i,j)$, and *K1* and *K2* are constants. The SSIM value ranges from -1 to 1. The value 1 denotes source image and fused image are same in all views.

4. *Mean absolute error:*

Mean Absolute Error (MSE) is used to determine the proximity between source image and fused image. The MAE can be expressed as

$$\sqrt{\frac{1}{M*N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}|F(i,j) - S(i,j)|}$$

Lower value represents greater similarity between reference image and fused image.

5. *Normalized Root Mean Square Error:*

RMSE is normally used to compare the difference between the reference image and fused image by directly computing the inequality in pixel values. When RMSE value is zero, the combined fused image is close to the reference image. RMSE is a better indicator of the spectral quality of fused image.

$$\sqrt{\frac{1}{M*N*255^2}\sum_i^M\sum_j^N\left(F(i,j) - S(i,j)\right)^2}$$

The NRMSE used in order to evaluate the effects of information changing for the fused image. The level of information loss can be expressed as a function of the reference image pixel and the fused image pixel, by using the NRMSE between reference image and fused images in k-band.

6. *Percentage Fit Error:*

Percentage Fit Error (PFE) is calculating the norm of the difference between the corresponding pixels of reference image and fused image to the norm of reference image. When PFE value is zero, it represents that both reference image and fused images are similar and value will be increased when the merged image is not similar to the reference image.

$$\frac{Norm(I_S - I_F)}{Norm(I_S)} * 100$$

IV. PERFORMANCE ANALYSIS AND RESULTS

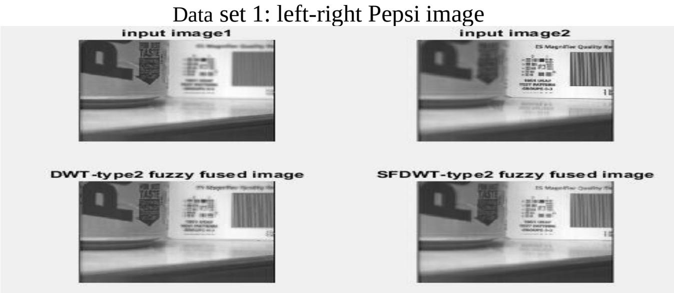
The performance of proposed fusion method to determine its efficiency and also results are evaluated in following table.

COMPARISON OF SF-DWT TYPE2 AND SF-DWT IMAGE FUSION TECHNIQUES INTERMS OFNCC, PSNR, SSIM, MAE, NRMSE, PFE.

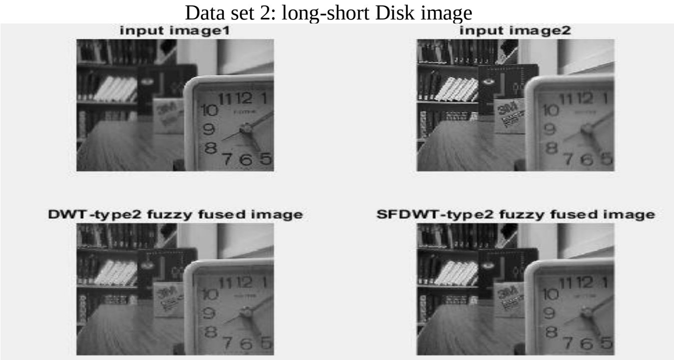
Image/parameters	METHODS	NCC	PSNR	SSIM	MAE	NRMSE	PFE
Pepsi	SFDWT-TYPE2	0.9992	35.3338	0.9951	2.4741	0.0171	1.8323
	DWT-TYPE2	0.9982	31.9231	0.9893	3.1587	0.0253	3.3383
Disk	SFDWT-TYPE2	0.9980	31.4506	0.9884	3.9279	0.0268	2.1660
	DWT-TYPE2	0.9951	27.5001	0.9712	5.9556	0.0422	4.1390
Clock	SFDWT-TYPE2	0.9979	33.0450	0.9898	2.9817	0.0223	3.7974
	DWT-TYPE2	0.9945	28.7836	0.9733	4.5417	0.0364	6.6025
Toy	SFDWT-TYPE2	0.9982	33.7432	0.9944	3.2560	0.0206	3.5265
	DWT-TYPE2	0.9970	32.5332	0.9923	3.6531	0.0237	3.1221
Aero plane	SFDWT-TYPE2	0.9991	29.1705	0.9864	3.4824	0.0348	1.3553
	DWT-TYPE2	0.9986	26.4862	0.9750	4.2441	0.0474	2.1983
Medical image color	SFDWT-TYPE2	0.8093	63.1320	0.9995	0.0765	0.0031	32.2598
	DWT-TYPE2	0.6572	61.6458	0.9989	0.0863	0.0088	46.8716
Medical image gray	SFDWT-TYPE2	0.9864	24.8183	0.9720	8.1639	0.0796	12.3469
	DWT-TYPE2	0.9267	17.7097	0.8490	13.2170	0.1302	26.2420

The quality measures of different kinds of data sets are to determine the spatial frequency discrete wavelet transform type-2 logic method is better than discrete wavelet transform type-2 logic method. And also improve quality of image.

Data set 1: left-right Pepsi image



Data set 2: long-short Disk image



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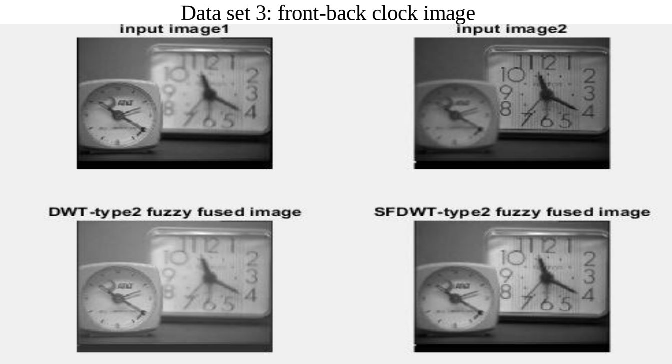
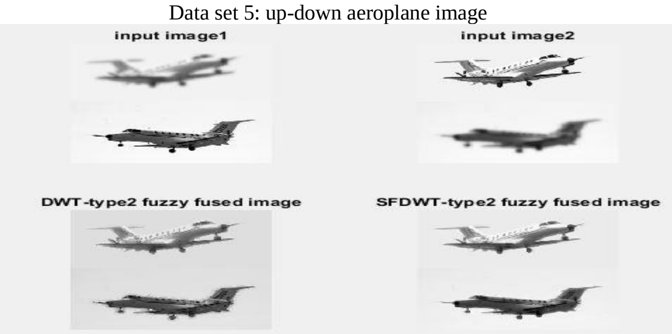
Data set 3: front-back clock image

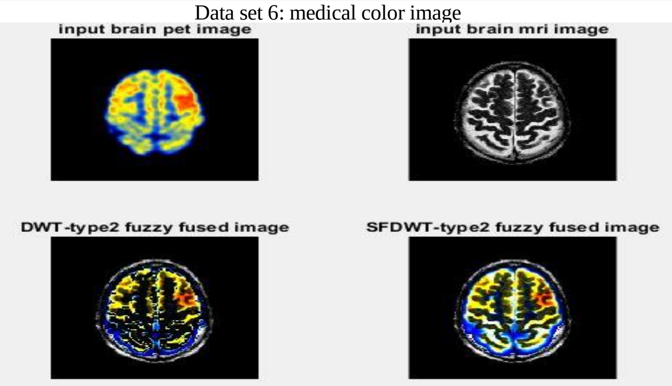


Data set 4:multifocus toy image

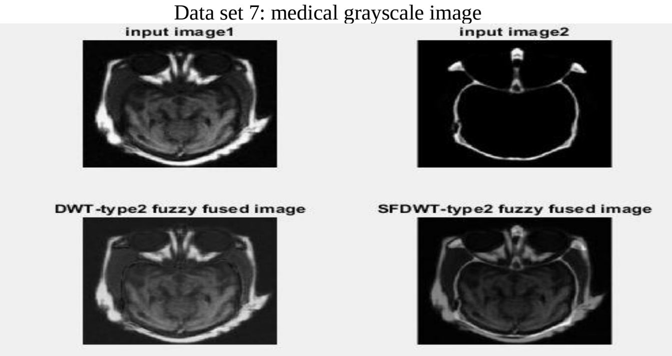
Data set 5: up-down aeroplane image



Data set 6: medical color image



Data set 7: medical grayscale image



The above Spatial frequency discrete wavelet transform type-2 fuzzy logic method is to determine subjective and objective analysis.

A. Subjective analysis:

The CT- MRI brain images, up-down aero plane images, left-right pepsi image are used as input images for experimental purpose. Fused images (result of different fusion method) arranged as discrete wavelet transform type-2 fuzzy logic and proposed spatial frequency discrete wavelet transform type2 fuzzy logic system. From the evaluation, it is observed that the visibility of image is increased in the results of proposed spatial frequency discrete wavelet transformtype2 fuzzy. when compared with the results of other methods. The proposed method gives better visualization because of the most important features are chosen based on the higher value of fuzzy entropy to fuse the low subbands coefficients. The entropy is important factor for fusion of images and it gives texture information of the image. Hence, the proposed method gives better result than the existing method.

B. Objective analysis:

Using subjective analysis, we cannot determine the completely fused image. Thus, objective analysis is results in fused images with measures mentioned in the previous section performance evaluation measures. For each measure, the result obtained from the proposed spatial frequency discrete wavelet transform type2 fuzzy logic method is compared with DWT-type2 fuzzy logic fusion method. The comparative analysis of different performance evaluation measures is tabulated in Table 1. From the result, one can observe that the proposed spatial frequency discrete wavelet transform type2 fuzzy logic method produces a better result than the other existing fusion methods.

CONCLUSION AND FUTURE SCOPE

In medical imaging, information processing technologies are providing many types of medical images for clinical diagnosis, monitoring and analysis. The medical images are widely used in disease diagnosis, surgery, and radiotherapy. In military applications, the major issue is how effectively spectral information is protected, while simultaneously improving the spatial information. In order to overcome this problem, novel approach is proposed for fusion of images obtained from different modalities based on spatial frequency discrete wavelet transformation and type-2 fuzzy logic method. The proposed technique based on spatial frequency is found to be a better version of existing standard DWT type2 fuzzy logic image fusion technique. The quality of the proposed technique is analyzed, visually, quantitatively, using subjective and Objective performance evaluation measures. Here, spatial frequency two-level DWT decomposition is used to bring out the low-frequency and high-frequency subbands. This makes calculation is simple. For fusion process, Type-2 fuzzy logic and average fusion rule are applied to low-level subbands and high-level subbands respectively. The fusion rule is applied on low-level sub-images to include the most important features with the highest degree of certainty. Then, by using inverse discrete wavelet transform fused images are reconstructed. Evaluation results of the fused image based on MAE, PSNR, NCC, NRMSE, PFE and SSIM measure analyses, it can be vividly comprehending that the proposed technique Spatial frequency discrete wavelet-transform type-2 fuzzy logic fusion method provides better results over the existing methods. In future work researches is based on combining multiple fusion algorithms and also develop algorithms to overcome fusion constraints.

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