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Interval Type 2 Fuzzy Logic Based Multifocus Image Fusion

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Abstract— Multifocus image fusion is a process of obtaining one clear image using a set of images where some regions in each image are in focus and other regions are out of focus. Extracting the in-focus regions from the input images and fusing them together into a new image is a major task. There are various approaches used for this purpose. A novel approach based on Interval Type 2 Fuzzy Logic combined with discrete wavelet transform has been experimented and the results have been presented in this paper. Mamdani and Sugeno Type fuzzy logic systems have been tested and results are compared with Type 1 Fuzzy Logic systems. Better results are obtained for Type 2 Sugeno fuzzy logic system.

Keywords—Discrete Wavelet Transform, Image Fusion, Multifocus Image, Type 2 Fuzzy Logic, Mamdani FLS, Sugeno FLS

I. Introduction

Image fusion is a process of integrating images of the same scene obtained from various sources. The input images must be registered. The fused image will contain the best features of the component images and hence will contain more relevant information than any of the individual images. There are various fields where image fusion plays an important role. One such field includes multifocus image fusion where two or more images whose points of focus is different are fused. Medical image fusion is another field where fusion of magnetic resonance imaging (MRI), positron emission tomography (PET) and single photon-emission computer tomography (SPECT) images is performed. Multisensor image fusion also includes fusion of images obtained from visible range sensors, infrared sensors, thermal sensors etc. Fusion of visible band and infrared images helps pilots to land aircraft in poor visibility [1]. Fusion of remotely sensed images obtained from different sources like satellites or remote cameras is yet another field of application of image fusion. Multitemporal images can also be fused.

Multifocus images are obtained by the same sensor. The point of focus in each image will be different. After fusion, all the regions appear to be in focus. The challenge here is to select the in focus region in each image and include it in the output fused image. The objects in the scene which are in focus appear clearer than the objects which are not in focus. Various image fusion techniques are available in literature for performing multifocus image fusion. Some of them include weighted averaging, principal component analysis, multiresolution based image fusion, fuzzy logic etc. Fuzzy logic based fusion techniques perform better than other techniques as they are basically developed handle uncertainties and imprecision [2].

The process of performing image fusion is divided into three types (i) Pixel-based (ii) Feature-based and (iii) Decision based. In pixel-based method, each set of corresponding pixels of the source images, mathematical operations like maximum, average, weighted average etc. is applied to obtain the fused image. Fuzzy logic or neural network can also be used to decide whether each pixel belongs to in focus of out of focus region. In feature level based method, features, for example, texture, are extracted from the source images and based on the characteristics of the features, some selection criteria is used to decide whether the extracted features should move to the output image. In decision based method, first objects are detected and classified. Then they are given as input to the fusion algorithm [3].

The aim of the proposed work in this paper is to apply Interval Type II fuzzy logic (IT2FL) to fuse multifocus images and compare the results with Type 1 fuzzy logic (T1FL). Discrete Wavelet Transform is used to enhance the quality of the performance and to reduce the time complexity as the fuzzy inference is applied only at the lowest resolution image.

I.I Discrete Wavelet Transform

An analysis of image fusion techniques based on DWT is performed in [4]. It is shown that wavelet transforms when combined with other conventional methods produce better results. At each level of the wavelet transform, four sub images of size reduced by half in both the dimensions, are produced. They are obtained by passing a high pass filter and a low pass filter along the rows and the columns. The sub images represent vertical components, horizontal components, diagonal components and approximation components. In the proposed approach, the vertical, horizontal and diagonal components are fused by using the maximum value at each pixel. Fuzzy logic approach is used to fuse the approximation components.

I.II Type 1 Fuzzy Logic System

Various researchers have applied fuzzy logic to fuse images. Finding a mathematical relation between the input images to form the fused images is not easy using crisp logic. Fuzzy logic is a tool that is utilized when there is uncertainty [5]. The region of the image which should appear in the output image is better decided by human experts. The best tool to convert this knowledge into a mathematical form is fuzzy logic. Fuzzy sets, a set of membership functions and fuzzy rules are defined for this purpose.

The fuzzy sets and fuzzy logic was proposed by Zadeh [6]. It is based on the membership functions represented by $\mu_A(x)$ which indicates the degree of membership of element x in fuzzy set A [7]. Fuzzy image processing consists of image fuzzification, fuzzy inference system and defuzzification [1]. Fuzzy sets were introduced to model vagueness in a system [8]. Classical sets are special cases of member functions of fuzzy sets taking only values 0 or 1. The membership function values can be in the real unit interval [0 1]. Fuzzy logic based image fusion is performed by [9], where neuro-fuzzy approach called ANFIS is used. [10] uses Fisher classifier to obtain a decision map and then fuzzy logic is used to define the rules based on the decision map.

Type 1 Fuzzy Logic System (T1FLS) consists of four components (i) Fuzzifier (ii) Rules (iii) Inference Engine (iv) Defuzzifier as shown in Figure 1 [11]. Fuzzifier converts crisp inputs into fuzzy sets. Fuzzy set is characterized by a membership function. Triangular membership function for type 1 fuzzy set (T1FS) is shown in figure 2. Rules are a collection of if-then statements. They are provided by domain experts or can be extracted by numerical data.

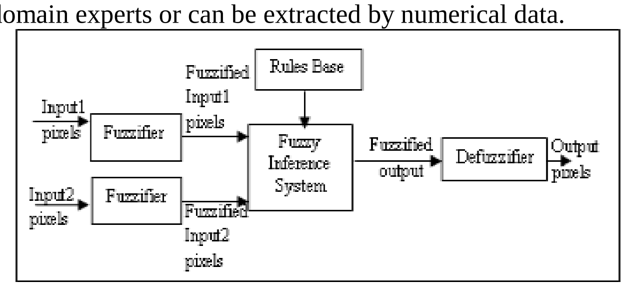

Figure 1 Type 1 Fuzzy Logic System

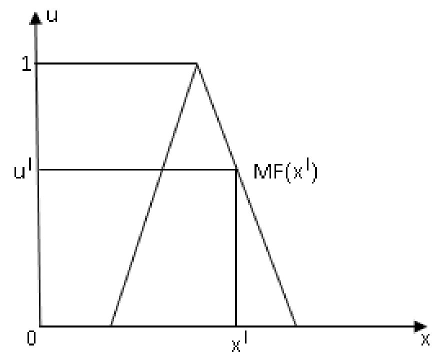

Figure 2 Triangular membership function for Type 1 Fuzzy set

The inference engine combines the rules using inferential procedures. It actually maps input fuzzy sets into output fuzzy sets. There are two types of fuzzy inference methods, (i) Mamdani's Fuzzy Inference method introduced in 1975 and (ii) Takagi-Sugeno Fuzzy Inference method introduced in 1985. The output of Mamdani's Fuzzy Inference method is a fuzzy set which has to be defuzzified further. The output of Sugeno's method is a crisp value and hence does not require defuzzification. Sugeno's method is used to model inference systems in which the output membership functions are linear or constant. The defuzzifier maps the output fuzzy sets of the inference engine to crisp values.

I.III Type 2 Fuzzy Logic System

L.A.Zadeh, in 1975, introduced type 2 fuzzy sets (T2FS) [12]. They are used to provide additional degrees of freedom so that lots of uncertainties can be handled and better performance can be obtained. T2FS minimize the effects of uncertainties in rule based fuzzy logic system. Type 2 Fuzzy Logic System (T2FLS) has five components (i) Fuzzifier (ii) Rules (iii) Inference Engine (iv) Type Reducer (v) Defuzzifier.

Fuzzifier in T2FLS converts crisp inputs into T2FS. The differences between T1FS and T2FS are as follows. T1FS has a crisp membership function whereas a T2FS has fuzzy membership function. Membership function of a T1FS is two dimensional whereas membership function of a T2FS is three dimensional as shown in figure 3 [13].

The Membership function of a T1FS is represented mathematically as u=MF(x) where *x* is an element of X consisting of range of inputs. At each value of x, there is one membership function value as depicted in figure 2. Type 2 Membership function (T2MF) is expressed as $\mu(x,u)$ where *x* is an element of X and *u* is the membership function (MF) value or grade. At each value of *x*, there are up to *N* membership function values, $MF_1(x)$, $MF_2(x)$,…..$MF_N(x)$ as shown in figure 4. Each Membership function $MF_i(x)$ has a weight w_{xi} associated with it. In figure 3, these weights are represented as vertical lines with weight value on the top. In general T2FS *w* is defined over a range of values. If the weighting is uniform, as shown in figure 4, this T2FS is called as interval type 2 fuzzy set (IT2FS) [14]. If all uncertainties in a T2FS disappear, T2FS reduces to T1FS. The operations, such as union, intersection and complement operations can be performed on T2 fuzzy sets.

In order to visualize a T2FS, its footprint of uncertainties (FOU) is plotted. The domain of T2FS is called the FOU. In figure 5, the shaded region is called the FOU. Figure 6 shows the FOU of Gaussian primary membership function. If secondary grades have uniform value, useful information is not conveyed and therefore it is discarded. This leads to Interval Type 2 Fuzzy Systems.

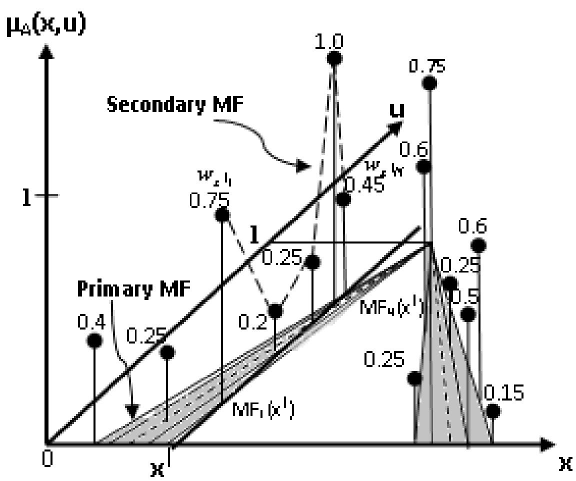

Figure 3 Triangular membership function for Type 2 Fuzzy set

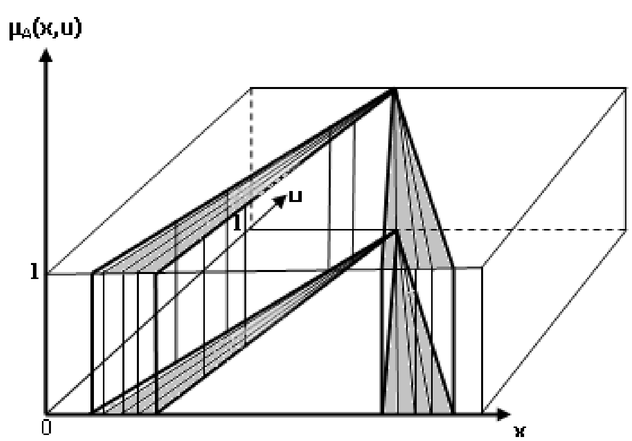

Figure 4 Triangular membership function for Interval Type 2 Fuzzy Set

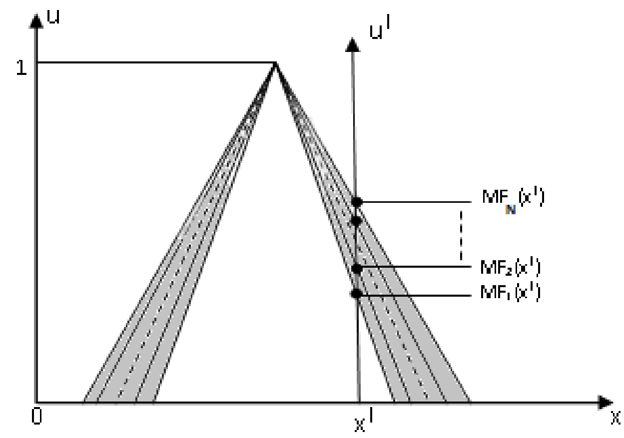

Figure 5 FOU of Type 2 Triangular Membership Function

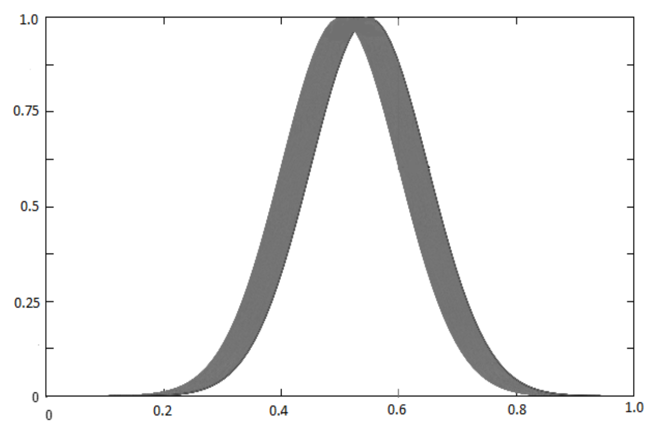

Figure 6 FOU of the Gaussian primary membership function

The three fuzzifiers used in Mamdani T2FLS are singleton, non-singleton type 1 and non singleton type 2 [15]. Sugeno T2FLS uses only singleton fuzzifier. Singleton is the most commonly used fuzzifier but it is not suitable when noise is present. In that case nonsingleton fuzzifier is used [16]. Singleton fuzzifier is as illustrated in figure 7.

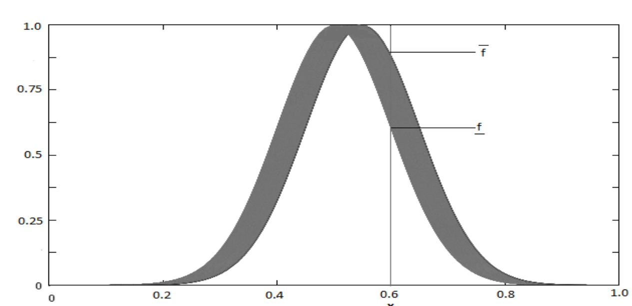

Figure 7 Singleton Fuzzifier

The fuzzified inputs $\bar{f}$ and $\underline{f}$ are found at the intersection of singleton at 'x' with the lower membership and upper membership function.

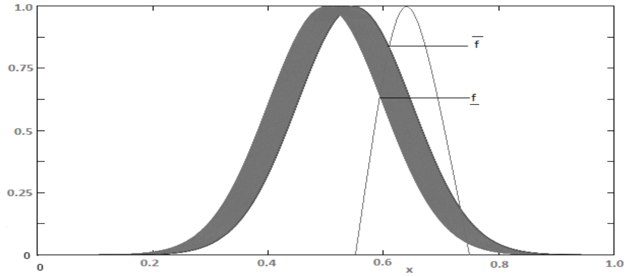

Figure 8 Non-Singleton Type 1 Fuzzifier

In non-singleton type 1 fuzzifier shown in figure 8, fuzzified inputs $\bar{f}$ and $\underline{f}$ are obtained at the intersection of Gaussian function whose mean is at 'x' with the lower membership and upper membership function.

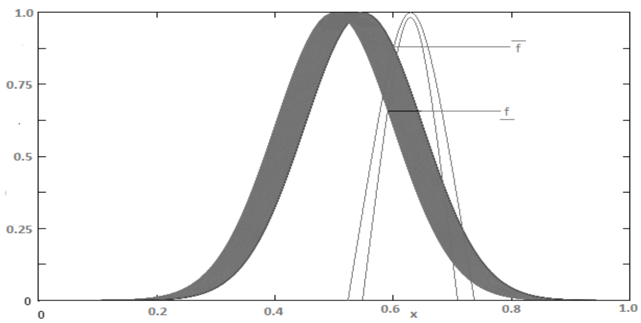

Figure 9 Non-Singleton Type 2 Fuzzifier

In non-singleton type 2 fuzzifier shown in figure 9, fuzzified inputs $\bar{f}$ and $\underline{f}$ are obtained at the intersection of set of Gaussian function whose centres are at 'x', with the lower membership and upper membership function.
Fuzzy Logic consists of a set of IF and THEN rules. The IF part is called as the antecedent and the THEN part is called the consequent. These antecedent and consequent are modeled as fuzzy sets. Rules are described by the membership functions of these fuzzy sets. In T1FL, the antecedents and consequents are all described by the membership functions of T1 fuzzy sets. In T2FL, some or all of the antecedents and consequents are described by the membership functions of T2FS. Therefore the rules do not change from T1FL to T2FL.

Inference Engine converts the inputs fuzzy sets to output fuzzy sets. It uses the rule base. The antecedents of the fired rules are combined using the fuzzy operators. For each rule, the common implication methods used are *product* and *minimum*. Figure 10 illustrates the *minimum* implication method for a singleton fuzzifier.

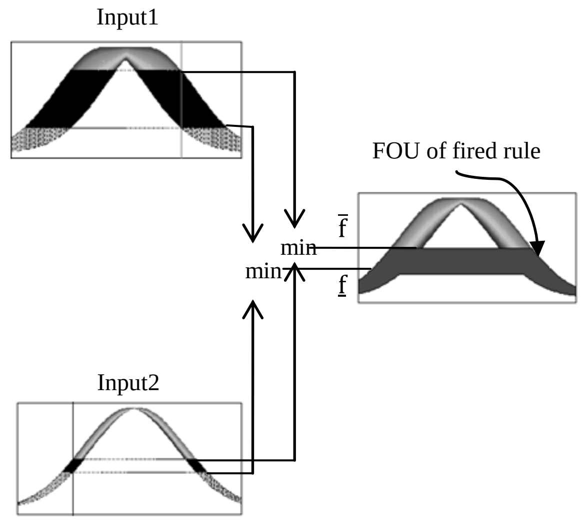

Figure 10 Fuzzy inference of a singleton fuzzifier

Type reducer converts the type 2 fuzzy set into type 1 fuzzy set. The commonly used type reducers are centre of sets and centroid. Figure 11 shows the centre of sets type reducer.

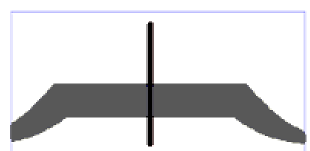

Figure 11 Type Reducer

The last step of a fuzzy logic system is defuzzification. In this step, the output fuzzy set is converted into a crisp number. There are various defuzzifiers like centroid, mean of maxima, maximum, etc.

II. METHODOLOGY

The block diagram of the proposed approach is illustrated in Figure 12.

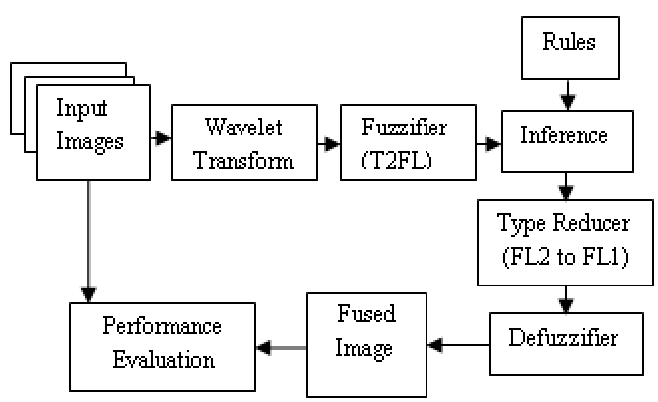

Figure 12 Block Diagram of the proposed approach

Algorithm

Step 1: Input the images to be fused

Step 2: Apply Discrete Wavelet Transform on the images upto desired level

Step 3: At each level fuse the detailed coefficients by selecting the maximum value

Step 4: Approximation coefficients are fused using steps 5 to step 10

Step 5: Extract and save the common regions of the images and copy to the output fused image

Step 6: Arrange the remaining area of the images into column vectors

Step 7: Set the fuzzy logic system as follows

- Step 7a: Select the type of fuzzifier
- Step 7b: Select the number of membership functions for input and output
- Step 7c: Frame the rules for fusion of the images
- Step 7d: Perform fuzzy inference. Two values $(\bar{f}, \underline{f})$ are obtained from antecedent operation. The fuzzified output is obtained by

$$\bar{\mu}_B^s = \bar{f} * \bar{\mu}_B$$

$$\underline{\mu}_B^s = \underline{f} * \underline{\mu}_B$$

  where '*' represents T-norm operators
- Step 7e: Apply 'Centre of sets' type reduction to convert the output into type 1 fuzzy set to obtain $\bar{y}$ *and* $\underline{y}$
- Step 7f: The crisp output is obtained by defuzzification given by

$$Y = \frac{\bar{y} + \underline{y}}{2}$$

Step 8: Obtain Inverse Wavelet Transform

Step 9: Convert the output columns into image

Step 10: Merge the background and the foreground images to obtain the final fused image

Step 11: Compute the various performance metrics using the input images and output images.

Eight Gaussian membership functions are used for both inputs and output as shown in Figure 13. The pixel values are divided into eight membership classes as very_dark (VD), medium_dark (MD), dark (D), light (L), very_light (VL), bright (B), medium_bright (MB) and very_bright (VB).

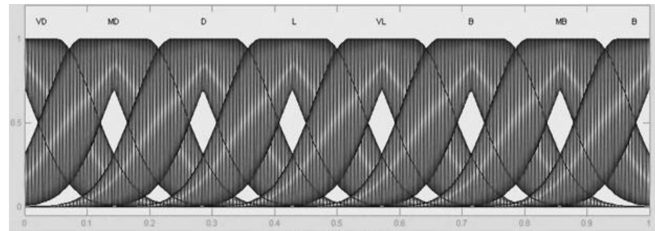

Figure 13 Gaussian Membership functions

The rules used to fuse multifocus images are shown in Table 1 The darker shades of the two images are selected for the fused image. As the clear regions compared to the blurred regions in multifocus images have high contrast, these rules are used.

Table 1 Rules for fusion

		Input Image 2							
		VD	**MD**	**D**	**L**	**VL**	**B**	**MB**	**VB**
Input Image 1	**VD**	VD	VD	VD	VD	VD	VD	VD	VD
	MD	VD	MD	MD	MD	MD	MD	MD	MD
	D	VD	MD	D	D	D	D	D	D
	L	VD	MD	D	L	L	L	L	L
	VL	VD	MD	D	L	VL	VL	VL	VL
	B	VD	MD	D	L	VL	B	B	B
	MB	VD	MD	D	L	VL	B	MB	MB
	VB	VD	VB	VB	VB	VB	VB	VB	VB

III. Results and Discussion

Performance metrics used to measure the quality of the fused image are divided into two sets. One set of metrics which are computed when ground truth image is not available are Entropy, Standard Deviation (SD), Cross Entropy (CE), Spatial Frequency (SF), Fusion Factor (FF), Fusion Quality Index (FQI), Fusion Similarity Metric (FSM) and Fusion Symmetry (FS). The set of metrics used when ground truth image is available are Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Percentage Fit Error (PFE), Signal to Noise Ratio (SNR), Peak Signal to Noise Ratio (PSNR, Correlation (CORR), Mutual Information measure (MI), Universal Quality Index (QI) and Structural Similarity Measure (SSM). The details of these metrics are given in [17].

The proposed approach is demonstrated using remotely sensed multifocus images and conventional multifocus images. Images of aircraft 'SARAS' are used as image set 1 [18]. In this set, one reference image and two complementary multifocus images are used. The images given in figure 14 and figure 15 are the input source images in set 1. Figure 16 and Figure 17 show the approximation and detailed coefficients of image 1 and image 2 respectively. Figure 18 shows the resultant fused image. The performance metrics of image set 1 are given in table 2 and table 3. Table 2 shows the results by comparing the input images with the output fused image. Table 3 contains the metrics by comparing the fused image with the ground truth reference image.

Figure 14 First Source Image I_1

Figure 15 Second Source Image I_2

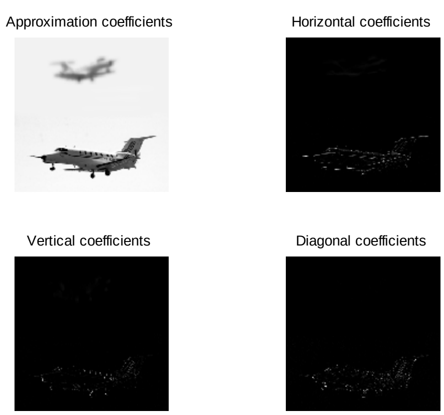

Figure 16 Wavelet transform coefficients of I_1

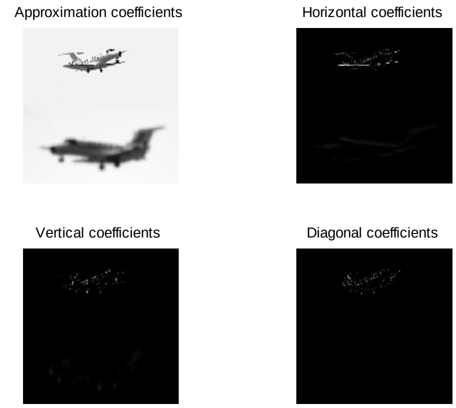

Figure 17 Wavelet transform coefficients of I_2

Figure 18 Output Fused Image F

Table 2 Evaluation Metrics without using reference image for image set 1

METRIC	FL TYPE 1	T2M	T1NST2M	T2NST2M	T2S
ENTROPY	3.9074	4.0471	4.0407	4.0370	**4.0556**
SD	0.1957	0.1941	0.1955	0.1949	**0.1987**
CE	**2.5070**	2.5071	2.5536	2.5616	2.7226
SF	0.0582	0.0499	0.0479	0.0469	**0.0592**
FF	0.34002	3.3983	3.3848	3.3695	**3.4066**
FQI	0.8543	**0.8545**	0.8501	0.8476	0.8540
FSM	0.7868	**0.7931**	0.7847	0.7815	0.7908
FS	**0.000853**	0.0025	0.0022	0.0021	0.0023

Table 3 Evaluation Metrics using reference image for image set 1

METRIC	FL TYPE 1	T2M	T1NST2M	T2NST2M	T2S
RMSE	0.0244	0.0360	0.0484	0.0520	**0.0237**
PFE	2.6735	1.82	5.2891	5.6842	**1.7845**
MAE	0.0074	0.0104	0.0132	0.0143	**0.0062**
CORR	0.9996	0.9992	0.9986	0.9984	**0.9988**
SNR	31.4583	28.0877	25.5324	24.9067	**36.4033**
PSNR	64.2834	62.5981	61.3205	61.0076	**65.7560**

MI	**1.839**	1.8271	1.8076	1.7966	1.8238
QI	0.8321	0.8203	0.8111	0.8077	**0.8375**
SSIM	**1.0**	0.9999	0.9998	0.9998	0.9998

The second image set consists of two complementary conventional multifocus images of clocks. Here reference image is not available. Figure 19 shows the input source images. Figure 21 shows the output fused image. Table 4 shows the evaluation metrics of image set 2. The best value for each metric is highlighted in the tables.

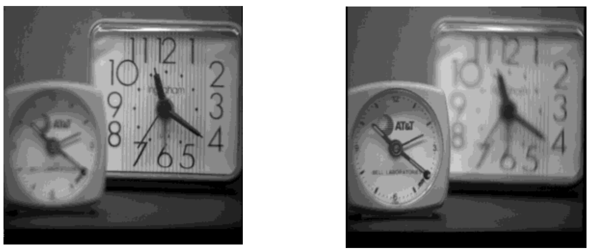

Figure 19 Input Source Images

Figure 20 Output Fused Image F

Table 4 Evaluation Metrics without using reference image for image set 2

METRIC	FL TYPE 1	T2M	T1NST2M	T2NST2M	T2S
ENTROPY	7.2949	7.3317	7.3260	7.3269	**7.3386**
SD	0.1954	0.1943	0.1937	0.1932	**1.1958**
CE	**0.1288**	0.1354	0.1394	0.1383	0.1457
SF	0.0347	0.0337	0.0344	0.0342	**0.0357**
FF	3.2712	3.2713	3.2624	3.2569	**3.2718**
FQI	0.8470	0.8465	0.8445	0.8438	**0.8475**
FSM	0.8279	**0.8291**	0.8267	0.8261	0.8262
FS	0.0073	0.0075	0.0071	**0.007**	0.0071

IV. CONCLUSION AND FUTURE SCOPE

A pixel level multifocus image fusion has been performed using interval type 2 fuzzy logic and wavelets. Both Mamdani and Sugeno Type fuzzy logic systems have been tested. The quality of the resultant fused image has been tested using fusion performance metrics. Our previous work had shown that type 1 fuzzy logic performs better that other commonly used approaches like averaging, principal component analysis and multiresolution techniques. Here the results are compared with type 1 fuzzy logic and found to be outperforming. The results show that Sugeno type fuzzy logic approach outperforms the other approaches. The future work is intended to apply hybrid technique combining type 2 fuzzy logic with texture analysis.

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