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Fusion of CT and MRI Images Based on Fuzzy Logic and Discrete Wavelet Transform

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Abstract— **Medical image fusion is used to integrate the essential features present in different medical images into a single image to improve the clinical accuracy to take better decisions. Multimodal medical image fusion combines the images obtained from different modalities like Positron Emission Tomography (PET), Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and others. CT scan provides detailed information on bony structures whereas MRI scan provides details on soft tissues. Fusion of these images is useful for doctors to diagnose and plan treatment for patients. In this paper, an image fusion methodology for fusing CT and MRI using fuzzy logic is presented. The bone tissue from CT image and the soft tissue from MRI image is segmented using Otsu's segmentation method. They are then fused using Fuzzy Logic and Discrete Wavelet Transforms. Experiments are conducted for both Mamdani type Fuzzy Logic System (FLS) and Sugeno type FLS with varying number of membership functions. The results are analyzed using various performance metrics. Sugeno FLS has produced better results compared to Mamdani FLS.**

Keywords—**Computed Tomography, Discrete Wavelet Transform, Fuzzy Logic, Image Fusion, Mamdani FLS, Magnetic Resonance Imaging, Sugeno FLS**

I. INTRODUCTION

Advances in medical imaging has led to the development of various techniques in image processing in order to provide more accurate and relevant information. Medical image fusion is one such field which is gaining more importance currently. As different imaging modalities capture different details, it becomes a challenge to the image processing community to develop sophisticated algorithms to extract the important details from each image and form a new fused image. This helps in better diagnosis, monitoring and analysis [1]. MRI data captures the details of the soft tissues and CT provides details of dense structures. PET is a nuclear imaging technique to provide details of blood flow [2].

Fusion of images obtained from these modalities into a single image reduces the memory requirement and also provides an improved image compared to each of the individual images. Most of the medical image fusion algorithms consider fusing of images obtained from any two modalities. Various methods and approaches have been used in developing these algorithms.

A survey on medical image fusion is presented by [1]. According to this survey, medical image fusion is characterized by (i) Image Fusion Method (ii) Modality used for imaging (iii) Imaging of organs under study.

Other than the conventional image fusion methods like addition, weighted averaging, taking maximum pixel value, soft computing techniques are also used. Most widely used approaches include using Neural Networks, Fuzzy Logic, Morphology methods, Support Vector Machines (SVM) and Principal Component Analysis (PCA).

It is observed that fuzzy logic approach gives better results for image fusion from visual perspective [3]. Weighted least squares filter method to fuse PET and MRI images has been proposed in [4]. The input images are decomposed into two components, base component and detailed component. Then weighted least squares filter followed by weighted average is used to fuse the images.

A Wavelet Transform based approach to fuse CT/MRI images and PET/MRI images has been proposed in [5]. This approach uses maximization approach for the approximation coefficients of the Wavelet Transform and uses the regional information entropy contrast degree to combine the high frequency components.

Wavelet based approach for fusion of medical images is also proposed in [6]. The low frequency components are fused using a visibility based scheme where the pixels having higher visibility among the two input images are selected into the fused image. The high frequency components are fused using variance as the selection parameter.

Similar approach is proposed in [7] where the maximum selection rule is used at each level of wavelet transform for fusing MRI and CT images. In [8] the approximation coefficients are fused by using average value. The detailed coefficients are fused by computing the entropy of 3 x 3 blocks and choosing the blocks value with largest entropy.

Fusion by using pulse coded neural network is performed in [9]. Recently fuzzy logic is being experimental for performing medical image fusion. Fuzzy logic and image local features are used to fuse MRI and PET images in [2]. The local features used are local variance and local blur.

A. Fuzzy Logic

Fuzzy logic approaches are used to handle uncertainty and when mathematical relations are not easily available. Fuzzy logic proposed by [10] has widespread applications. It is considered as a logic of approximation. It is an extension of Boolean logic to handle vagueness. Human reasoning acts as a source for writing fuzzy rules. In medical image fusion the logic is rather fuzzy than crisp. Therefore this approach is gaining momentum.

Fuzzy image processing approach is divided into 3 stages (i) Image Fuzzification (ii) Inference System (iii) Image defuzzification [11]. Fusion of CT and MRI images using fuzzy logic is performed in [12].

The input crisp values are converted to fuzzy values in the fuzzification process by fusing fuzzy sets and membership functions. A membership function computes the degree of belongingness in a fuzzy set in the range [0 1]. Based on the type of application membership functions like triangular, trapezoidal, Gaussian etc. can be chosen.

The fuzzy inference system is a set of rules and operations to evaluate the fuzzy output from fuzzy inputs. The rules are domain dependent and form the critical component of the fuzzy logic approach. The fuzzified output must be defuzzified by converting it into a crisp value. This process is called defuzzification.

B. Fuzzy Inference Process

Fuzzy inference process consists of formulation of a model to map the inputs to an output using fuzzy logic. This process comprises of five steps.

1. The first step is the fuzzification of crisp input values. It transforms the problem from a crisp logic space into a fuzzy logic space. Fuzzy logic space consists of fuzzy sets which are characterised by membership functions. They are used to map imprecision to numerical values between 0 and 1 which indicate the degree of belongingness of a vague value to a particular fuzzy set. Thus a crisp input is converted into a linguistic variable[10].
2. The second step is to apply fuzzy operators. Union, intersection and complementation are the fuzzy operators. They are applied when the antecedent part of a rule has more than one part. Union operation or the OR operation of two fuzzy values A and B can be implemented by using maximum(A,B) or probor(A,B)=A+B-AB. Intersection operation or the AND operations can be implemented by using minimum(A,B) or product(A,B). Complement operation on a set A is given by 1-A.
3. The next step is to apply implication method to obtain the output fuzzy set. The output of the second step is a single number obtained from the antecedent of the rule. For each rule implication method is applied to convert this number into a fuzzy set using the consequent fuzzy set. The weight of the must be taken into consideration before applying the implication method. Two common implication methods used are minimum and product.
4. After obtaining the output fuzzy sets for each rule, they must be aggregated into a single fuzzy set for each output variable. The common aggregation methods applied are (i) summing the output fuzzy set of each rule (ii) applying probabilistic OR operation (iii) taking maximum value across the range of input fuzzy set. The output of this step is a single fuzzy set.
5. The output of a fuzzy logic system is a crisp value and hence the final step of the inference process is to convert the fuzzy value into a crisp value. This step is known as defuzzification. To do so the output fuzzy set of aggregation process must be converted into a single number. The defuzzification techniques are centroid method, mean of maximum method, bisector method, smallest of maximum method and largest of maximum method.

Researchers have applied Mamdani and Sugeno type Fuzzy Inference Systems (FIS) for image fusion. The difference between the two is that the output of the aggregation step in Mamdani FIS is a fuzzy set which needs defuzzification whereas the output of a Sugeno FIS is a constant or a linear function.

The approach proposed in [12] fuses CT and MRI images by choosing the maximum value of the two pixels by using Mamdani type FIS. Neuro-fuzzy approach to fuse CT and MRI images is proposed in [13] but it is problem specific.

C. Discrete Wavelet Transform

The inherent multiresolution characteristic of DWT is exploited in many image processing applications. Another advantage of DWT is that it separates the low frequency and high frequency components. It is very useful while performing image fusion as high frequency components indicate the locations which contain important information in the input images. These features indicate the part of the image which should contribute to the output at any given location. The high frequency components contain details on vertical, horizontal and diagonal coefficients. The proposed approach uses hybrid approach which combines the advantages of fuzzy logic and DWT to fuse multimodal medical images.

D. Otsu's Segmentation Method

This is a nonparametric and unsupervised method that automatically selects the threshold for image segmentation. It computes an optimal threshold for segmenting images by using the zeroth and the first order cumulative moments of the gray-level histogram. This threshold is used to convert the image into binary images. The pixels lower than the threshold value are converted to black and others are converted to white. Hence this method is used in the proposed approach to segment CT images and MRI images. Only bone tissues are segmented in CT images and soft tissues are segmented in MRI images [14].

E. CT Images

Computed tomography or CT is a medical imaging technology that uses X-rays to create cross-sectional images of the inside of the body. It produces virtual slices of the body part being scanned to see what is inside without cutting it open. It gives information about size, shape and location of bony structures in human anatomy. They are used for diagnostic and therapeutic purposes in various medical disciplines.

CT scanning is done using an X-ray source and detector that are situated 180 degrees across from each other. They rotate 360 degrees around the patient, continuously detecting and sending information about the attenuation of X-rays as they pass through the body. To minimize the degree of scatter or blurring, very thin X-ray beams are used. X-ray attenuation is detected by detector & data acquisition system. A computer manipulates and integrates the acquired data by assigning numerical values based on the subtle differences in X-ray attenuation. Based on these values, a gray-scale axial image is generated that can distinguish between objects with even small differences in density [15].

F. MRI Images

MRI is a non-invasive diagnostic test that uses the power of magnets to take detailed images of the soft tissues of the body. It creates images using magnetic field, radio waves and a computer. The magnet creates a strong magnetic field that aligns the protons of hydrogen atoms in the body. They are then exposed to short burst of radio waves. This spins the various protons of the body and they produce a signal that is detected by the receiver portion of the MRI scanner. The signal emitted from different body tissues varies. The signal is processed by a computer and an image is produced. Images are produced as slices.

MRI scans are used to diagnose a variety of conditions from torn ligaments to tumours. MRIs are very useful for examining the brain and spinal cord. Air and bone appear black in the MRI scan as they do not respond to MRI signal. Bone marrow, spinal fluid, blood and soft tissues vary from the intensity of black to white. Bones and air appear black and soft tissues appear white in MRI scan [15].

G. Organization of the paper

In this paper, section I gives an introduction on medical image fusion and the different techniques used for fusing CT, MRI and PET images. It also gives a brief introduction on fuzzy logic, DWT, medical images. The proposed algorithm is given in section II. It also describes the Fuzzy Logic System (FLS) and fuzzy rules used in the work. Section III evaluates the results obtained using the proposed approach and compares with the results of other techniques. Section IV describes the various performance metrics used to evaluate the image fusion results. Section V gives the conclusion and scope for future work.

II. PROPOSED APPROACH

The proposed approach uses a hybrid method of fusing CT and MRI images. Discrete Wavelet Transform is used to utililize the multiresolution characteristic and also to apply fusion process separately on different frequency components. Fuzzy logic approach is used to fuse the approximation coefficients of the DWT. This increases the accuracy of the fusion process.

The high density bone tissues are segmented in the CT image. Soft tissues are segmented in the MRI image. Otsu's segmentation method is used for this purpose. These segmented tissues are superimposed into a fused image.

The other areas are fused using fuzzy logic and DWT. They are fused in such a way that the brighter regions among the two images are carried to the fused image. Gaussian membership functions are used for both input and output fuzzy sets. Experiments are conducted with varying number of fuzzy sets. 'Daubachies' wavelet transform is used.

A. Algorithm for the proposed approach

Step 1: Input CT and MRI images.

Step 2: Segment bony tissue region from CT image using Otsu's method.

Step 3: Segment soft tissue region from MRI image using Otsu's method.

Step 4: Fuse the segmented CT and MRI images by selecting the maximum value. Fusion of the other regions continues as shown in the following steps.

Step 5: Apply Discrete Wavelet Transform on the original input images up to the desired level.

Step 6: Repeat steps 7 to 17 at each level of DWT

Step 7: Perform segmentation as described in step 2 using the approximation coefficients of DWT

Step 8: Fuse the segmented coefficients by selecting maximum value and store in the intermediate fused image 'I_F'.

Step 9: Select the zero valued pixel positions in I_F into an array, 'p'.

Step 10: Copy the approximation coefficients at locations in 'p' from CT image into image I_1

Step 11: Copy the approximation coefficients at locations in 'p' from MRI image into image I_2

Step 12: Use $I_1$and I_2 as inputs to the FLS.

Step 13: Select the type of FLS, input and output membership functions, fuzzy operator, aggregation method and defuzzification method.

Step 14: Obtain the output pixel values using fuzzy inference system.

Step 15: Copy the output values to their corresponding locations in I_F.

Step 16: Fuse the detailed coefficients by selecting the maximum value of the two inputs.

Step 17: Apply Inverse Discrete Wavelet Transform on the fused approximation coefficients and detailed coefficients.

Step 18: At the input level, copy only the fused unsegmented pixels to the output image.

The block diagram of the proposed approach is shown in Fig.1.

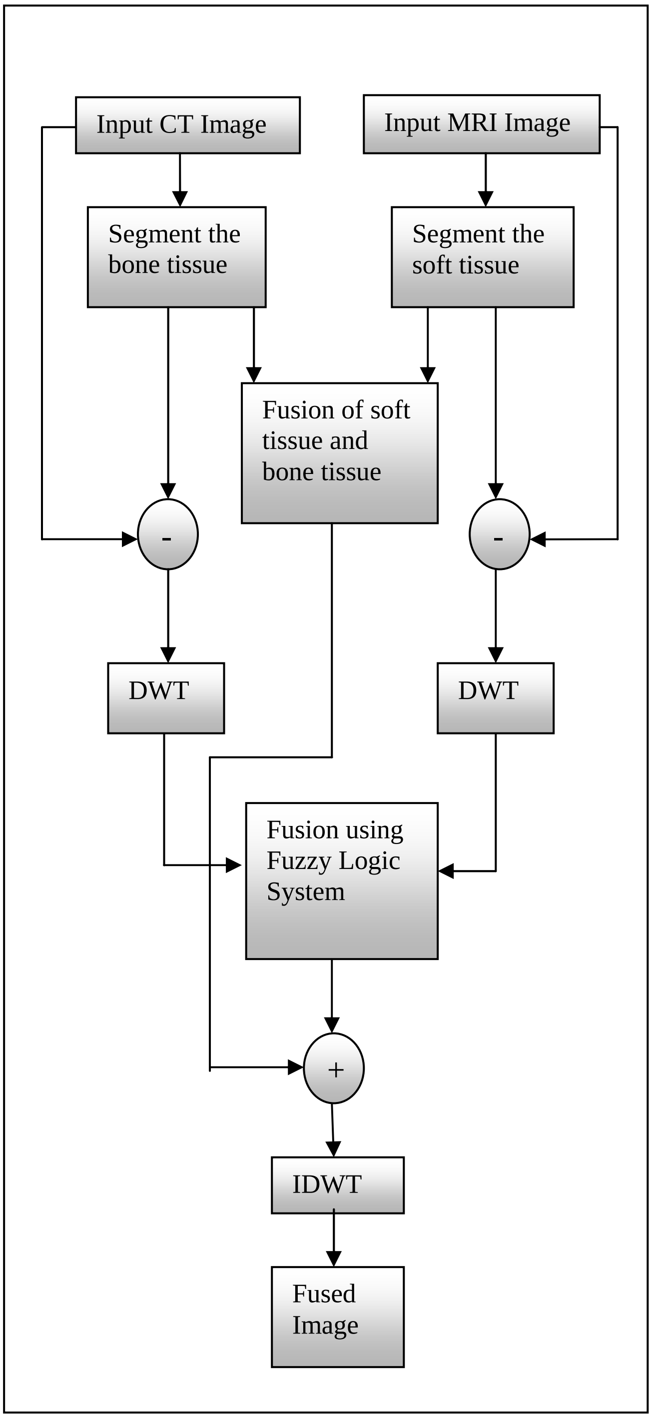

Fig. 1 Block Diagram of the proposed approach

B. *Fuzzy Logic System*

The fuzzy logic system used in the proposed approach is as shown in Fig. 2. Two images are fuzzified using Gaussian membership functions as shown in Fig 3. Eight fuzzy sets are used for both input and output. Mamdani type fuzzy inference system is used to evaluate the rules and produce the fuzzified output. Maximum value is used to perform 'OR' operation and minimum value is used to evaluate 'AND' operation. Defuzzified crisp output is obtained using centroid method.

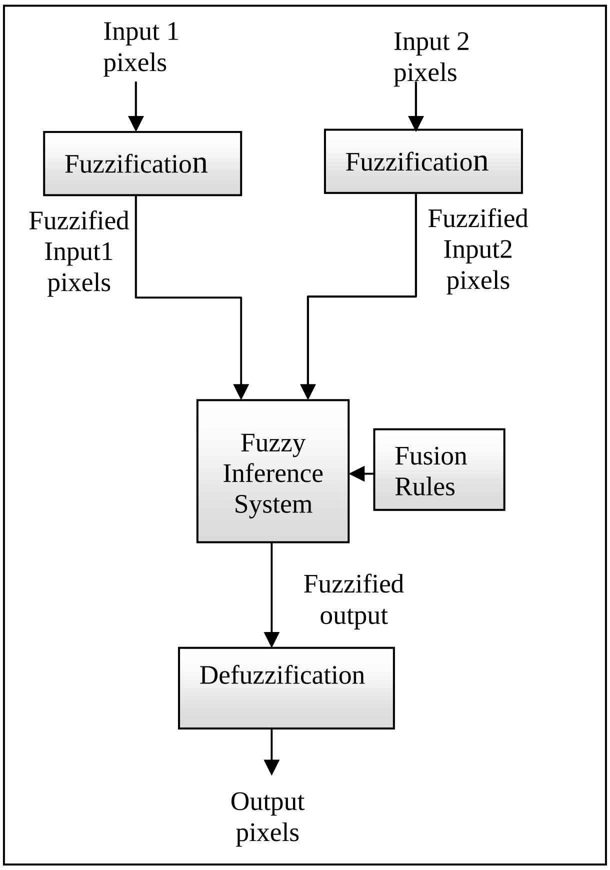

Fig. 2 Fuzzy Logic System used for image fusion

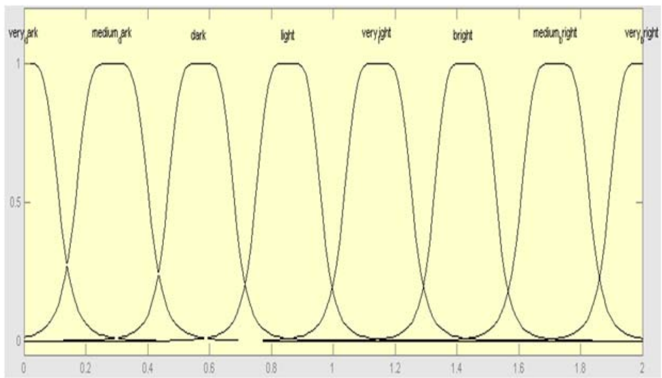

Fig. 3 Fuzzy sets used

C. *Fuzzy Rules*

The fuzzy rules have been framed based on the knowledge that fused image must contain the brighter regions from the input images. Therefore highest priority is assigned to the brightest value and then decreased for the darker pixels. The priority assigned to the eight fuzzy sets is as shown in table I.

TABLE I
PRIORITIES ASSIGNED TO FUZZY SETS

Fuzzy Set	Priority
Very dark	1
Medium dark	2
Dark	3
Light	4
Very light	5
Bright	6
Medium bright	7
Very bright	8

III. EXPERIMENTAL RESULTS AND ANALYSIS

Experiments are conducted with two sets of images. The first set consists of images when reference fused image is not available. This set is referred to as data set 1 which is obtained from online database “ATLAS”. The second set consists of images when reference fused image is available and it is referred to as data set 2. The results are discussed in sections A and B respectively.

A. Results obtained for Data Set1

The input original CT image and MRI images are shown in Fig.4and Fig.5 respectively. CT image after segmenting bone tissue is shown in Fig.6. Segmented soft tissue from MRI image is shown in Fig.7. The superimposed partially fused image containing both bone tissue and soft tissue is shown in Fig.8. This contains only the fusion of the segmented CT and MRI images. The final fused image is shown in Fig. 9.

Fig. 4 Original CT Image

Fig. 5 Original MRI Image

Fig.6 Segmented CT image

Fig. 7 Segmented MRI image

Fig. 8 Partially fused images

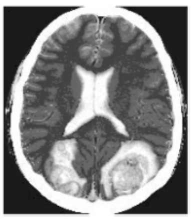

Fig. 9 Fused CT and MRI images

B. Results obtained for Data Set 2

The proposed approach has also been applied on images where the fused reference image is available. Fig. 10 and Fig. 11 show the input original CT and MRI images respectively. Fig.12 and Fig.13 show the segmented CT and MRI images respectively. Fig. 14 is the reference fused image. Fig.15 shows the final fused image using the proposed approach.

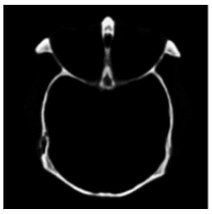

Fig. 10 Original CT Image

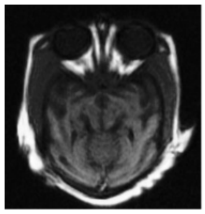

Fig. 11 Original MRI Image

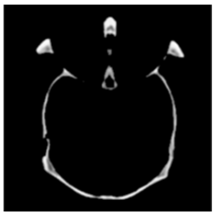

Fig.12 Segmented CT image

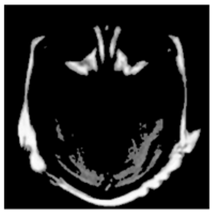

Fig. 13 Segmented MRI image

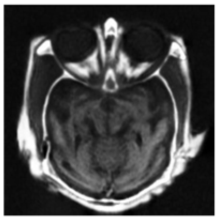

Fig. 14 Reference fused image

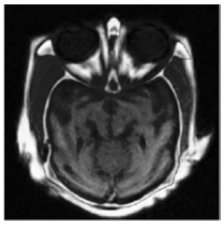

Fig. 15 Fused CT and MRI images using proposed approach

IV. PERFORMANCE EVALUATION

To evaluate the performance of the proposed approach the following metrics are used. For quality assessment of pixel-level image fusion when reference image is available, the metrics used are (i) Root Mean Square Error (RMSE) (ii) Mean Absolute Error (MAE) (iii) Percentage Fit Error (PFE) (iv) Signal to Noise Ratio (SNR) (v) Peak Signal to Noise Ratio (PSNR) (vi) Correlation (CORR) (vii) Mutual Information measure (MI) (viii) Universal Quality Index (QI) (ix) Structural Similarity Measure (SSM).

When the reference image is not available the performance metrics used are (i) Standard Deviation (SD) (ii) Entropy (E) (iii) Cross Entropy (CE) (iv) Spatial Frequency (SF) (v) Fusion Factor (FF) (vi) Fusion Symmetry (FS) (vii) Fusion Quality Index (FQI) (viii) Fusion Similarity Metric (FSM). The details of each of the metrics used are discussed in [16].

The parameters estimated for fusion of images in data set 1 is given in Table II. The proposed approach uses Sugeno FIS with eight membership functions. This table also contains similar parameters estimated for the other approaches available for medical image fusion in literature. Wavelet Transform method uses maximum value of the wavelet coefficients. It can be observed that the proposed approach gives better results for most of the parameters compared to the other available approaches. Table III shows the parameters estimated of the proposed approach on data set 2 in comparison with the other available techniques. The best value obtained for each parameter is highlighted.

TABLE III
PERFORMANCE METRICS OF DATA SET 1WHEN REFERENCE FUSED IMAGE IS NOT AVAILABLE

METRIC	USING SIMPLE MAXIMUM	USING PCA APPROACH	USING WAVELET TRANSFORM	PROPOSED APPROACH
ENTROPY	6.7869	1.4876	1.4297	**6.9179**
SD	0.2968	**0.3178**	0.2989	0.292
CE	0.7330	**0.1844**	0.3472	1.1716
SF	0.1587	0.1430	0.1518	**0.1592**
FF	2.3129	2.4909	2.3730	**2.4922**
FQI	0.5909	0.4354	**0.6176**	0.5912
FSM	0.8126	0.7076	0.7932	**0.8391**
FS	0.0400	0.0264	0.0235	**0.0401**

TABLE IIII
PERFORMANCE METRICS OF DATA SET 2WHEN REFERENCE FUSED IMAGE IS AVAILABLE

METRIC	USING SIMPLE MAXIMUM	USING PCA APPROACH	USING WAVELET TRANSFORM	PROPOSED APPROACH
RMSE	0.0503	0.0521	0.1304	**0.0500**
PFE	14.4086	14.9385	37.3597	**13.7419**
MAE	0.0270	0.0275	0.0465	**0.0263**
CORR	0.9893	0.9885	0.9189	**0.9895**
SNR	**16.8275**	16.5139	8.5519	16.0588
PSNR	**61.1491**	60.9923	57.0113	60.7648
MI	1.6628	1.6560	1.4265	**1.6765**
QI	0.8973	0.8970	0.7970	**0.8977**
SSIM	0.9997	0.9997	0.9979	**0.9997**

Results obtained for Mamdani and Sugeno FIS for varying number of membership functions are shown in Fig.16 through Fig. 23. The performance metrics are obtained for data set 1. It is seen that Sugeno FIS gives better results compared to Mamdani FIS for fusion of CT and MRI images.

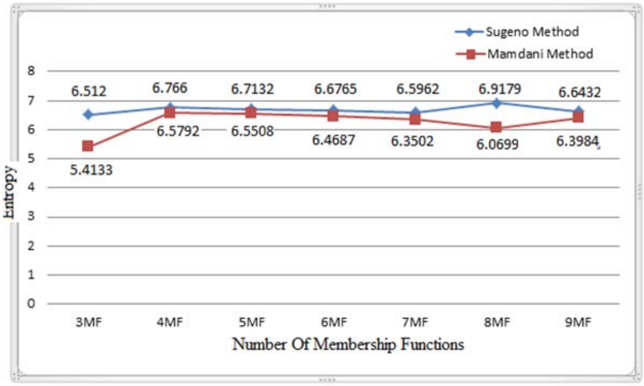

Fig.16 Entropy

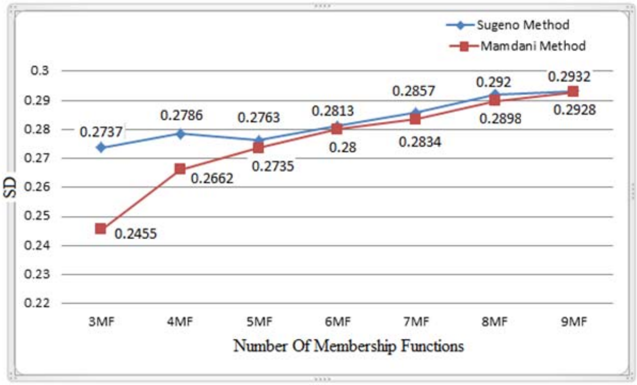

Fig.17 Standard Deviation

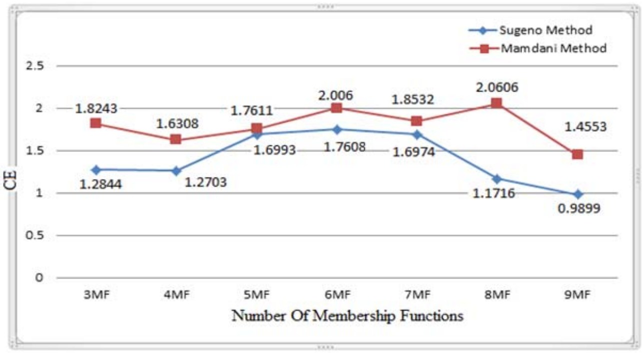

Fig.18 Cross Entropy

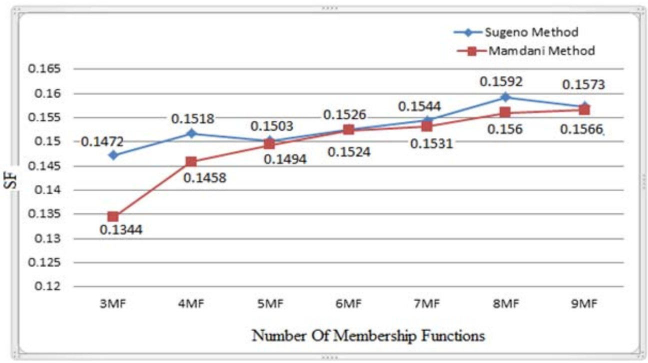

Fig. 19 Spatial Frequency

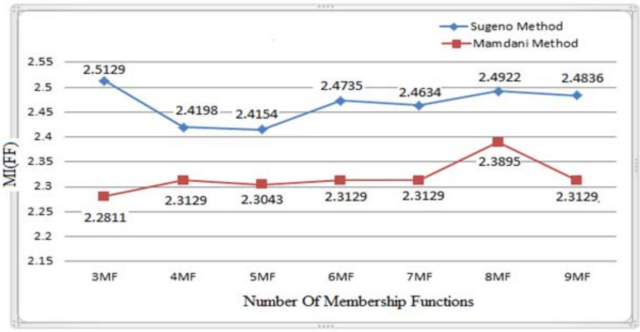

Fig.20 Fusion Factor

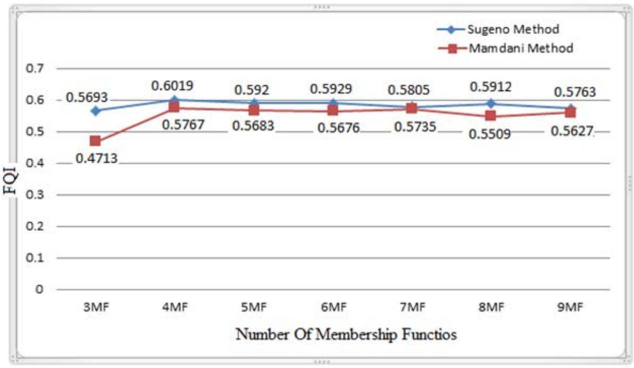

Fig.21 Fusion Quality Index

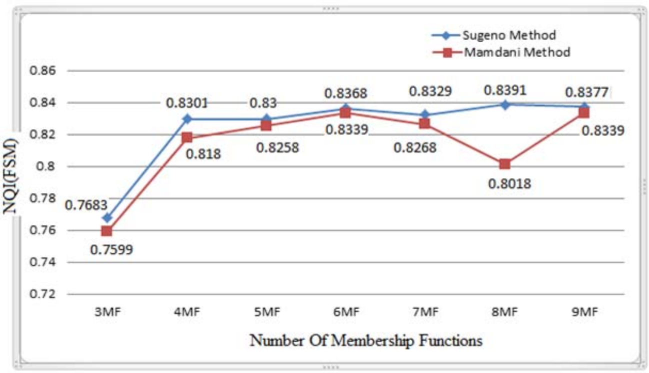

Fig. 22 Fusion Similarity Metric

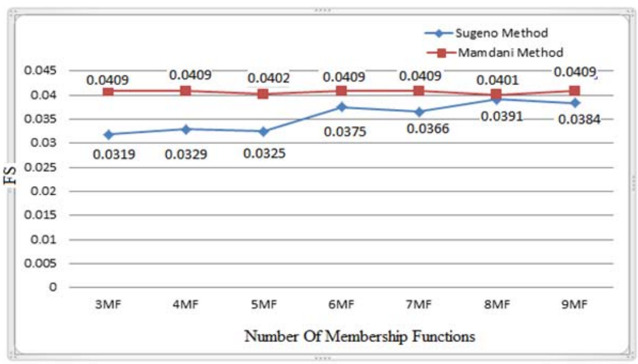

Fig. 23 Fusion Symmetry

The histograms obtained for the original CT, MRI and fused images of data set 1 and data set 2 are shown in Fig. 24 and Fig. 25 respectively. The histogram of CT image is shown in blue colour. The histogram of MRI image is shown in green colour and that of fused image is shown in red colour. It is observed from the histogram that the fused image is the summation of the other two. This is because the features of both CT and MRI images are present in the fused image.

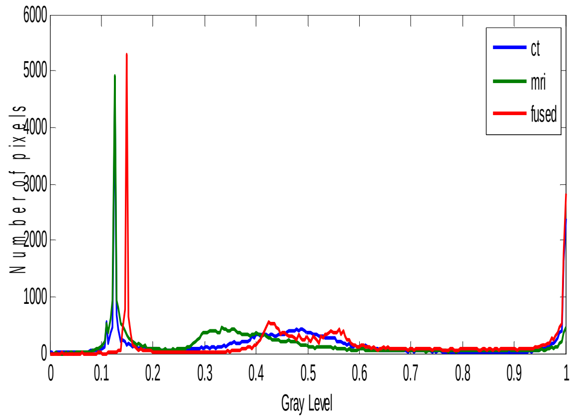

Fig. 24 Histogram of data set 1

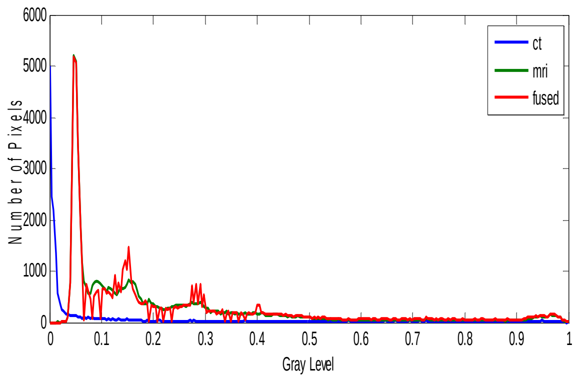

Fig. 25 Histogram of data set 2

V. CONCLUSION

Fusion of CT and MRI images helps in treatment planning for radiotherapy by enabling accurate target volume localization. The challenge in such a fusion is to retain the bone tissue present in the CT image and the soft tissue present in the MRI image. In this paper, a novel hybrid approach has been proposed for fusion CT and MRI images. It is assumed that the CT and MRI images used for fusion are already registered. The advantage of this proposed approach is that it segments the bone tissue in the CT images and the soft tissue from the MRI images and then superimposed. The other regions are fused using fuzzy logic and discrete wavelet transform. The experiments have been conducted with varying number of membership functions for both Mamdani and Sugeno FLS. It has been observed that Sugeno FLS outperforms Mamdani FLS. Similar approach can be used for the fusion of other medical images.

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