MAMDANI AND SUGENO FUZZY INFERENCE SYSTEM BASED MULTIMODAL MEDICAL IMAGE FUSION

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Abstract - *Multimodal medical image fusion is a process of extracting information from different medical images to obtain a single image called fused image. Fused image analysis is extensively used by clinical professionals for quick diagnosis and treatment of critical diseases. This project is developed using mamdani and sugeno fuzzy inference system for integrated multimodal medical images. Mamdani and sugeno based fusion helps in preservation as well as effective transfer of detailed information present in input images into a fused image. Image Fusion not only provides better information but also minimize the storage cost by minimizing the memory requirement for storage of multiple images. The proposed work is effective and generates better fused images compared to existing techniques such as discrete wavelet transform (DWT) and non-sub sampled counterlet transform (NSCT). The fused image is also compared with quality metrics such as Entropy (E), Mutual Information (MI) and Edge based quality metric (QAB/F). The superiority of the proposed method is presented and is justified using subjective and objective analysis.*

***Key Words*: Fuzzy logic, Medical images, Segmentation , Matlab, Image processing.**

1.INTRODUCTION

The technique of combining all the relevant information from several photos into one or fewer, generally single, images is known as image fusion. By keeping all the data in a single input image rather than using numerous input photos, image fusion reduces storage costs. The primary goal of Image Fusion is to create images that are more suitable and intelligible for both human and machine perception, in addition to minimizing the quantity of data. Image fusion is employed in numerous medical applications, including radiation therapy, neurology, cardiology, and oncology, because of its better and unique information representation. The primary goal of picture fusion is to remove any artifacts while maintaining all relevant and accurate information from the original photos. Various performance measures, such as entropy, correlation coefficient, peak signal to noise ratio, root mean square error, standard deviation, structure similarity index, high pass correlation, edge detection, average gradient et cetera, are used for objective evaluation, which verifies the image quality. The information content of images can be measured by entropy, the registered and fused images can be compared using the correlation coefficient, the fused image's clarity can be assessed using the average gradient, the cumulative error between the original and fused images can be calculated using the root mean square error, and image error can be quantified using the peak signal to noise ratio. Pixel-level, feature-level, and decision-level image fusion algorithms are among the many that have been developed and published in the literature. Based on the brightness of each pixel, pixel level algorithms directly fuse the raw input images. Using their distinguishing characteristics, such as edges and line segments, feature-level algorithms combine the input images. To create higher-quality images, decision level algorithms directly integrate image descriptions, either as relational graphs or as probabilistic variables. Pixel level image fusion methods are more information-efficient than feature-level and decision-level algorithms. These pixel-level techniques are more computationally efficient while also being simple to use. For multimodal Image Fusion, pixel-level methods are therefore recommended.

1.1 Motivation

Utilizing Mamdani and Sugeno Fuzzy to merge the medical images

1.2 Objectives

- To improve diagnosis, combine numerous images into one to get essential information.
- To increase the precision of the diagnosis.
- To improve the effectiveness of item identification.

2. Literature Survey

The fuzzy inference systems of MAMDANI and SUGENO are two well-liked techniques in fuzzy logic for inference and judgment. They have been widely used in many other disciplines, such as medical image fusion, which provides a more thorough and accurate picture of the underlying anatomical structures or clinical states by combining complimentary information from numerous medical imaging modalities.

In order to improve the presentation and understanding of medical data, multimodal medical image fusion attempts to combine data from several imaging modalities, including positron emission tomography (PET), computed tomography (CT), and magnetic resonance imaging (MRI). Treatment planning, surgical guiding, and diagnostic accuracy can all be enhanced by the fusion process.

1. Mamdani Fuzzy Inference System in Medical Image Fusion.
2. Sugeno Fuzzy Inference System in Medical Image Fusion.
3. Hybrid and Adaptive Approaches.
4. Performance Evaluation and Comparison.

The research on fuzzy inference systems Sugeno and Mamdani in medical image fusion emphasizes how well these systems can combine complimentary data from various imaging modalities to enhance visualization and diagnostic precision. Still up for debate, however, are the best fuzzy inference system to use and how to create efficient fuzzy rules. There is constant work to create more reliable and flexible approaches that are suited to certain clinical scenarios.

2.1 Existing systems

Numerous systems have been created and documented in the literature, including the Mamdani and Sugeno Fuzzy Inference Systems, which are commonly used in multimodal medical picture fusion. Here are a few instances of current systems built using these fuzzy inference techniques:

a. A technique for combining brain MRI and PET images that was suggested by Mahurt et al. (2016). The system makes use of a Mamdani fuzzy inference system, whose rules are created using information on pixel intensity from the input photos and expert knowledge. Comparing the fused pictures to previous fusion approaches, the performance was better when assessed using mutual information and edge-based criteria.
b. A technique for combining brain CT and MRI images that was created by Umar et al. (2019). To define the fuzzy rules, the proposed Mamdani fuzzy inference system makes use of spectral and spatial information from the input pictures. A range of criteria, including mutual information, edge preservation, and the structural similarity index (SSIM), were used to assess the system and show how well it preserved significant details from both modalities.
c. A method for merging MRI and functional MRI (fMRI) images was developed by Siddique et al. (2020). Rules based on pixel intensity and contextual information from the input photos are included by the Mamdani fuzzy inference system. Tested on many brain datasets, the system demonstrated better performance than alternative fusion techniques when the fused pictures were assessed using criteria like mutual information and SSIM.

3. PROPOSED METHOD

The toolbox for the fuzzy inference system (FIS) is used to change the membership values. There are several kinds of fuzzy inference systems. Mamdani-style FIS Sugeno type FIS is a set of MATLAB tools that includes rule viewers, membership function editors, surface viewer rule editors, and FIS editors. FIS is comprised of membership functions that are constructed for both input and output variables. determining the membership value for the image's gray level, which includes the variation between the gray levels, maximum gray level, and minimum gray level. The pixels are given their new membership values according to changes in intensity level.

3.1. The fuzzy inference system of Mamdani

When Mamdani fuzzy inference was initially presented, it was a technique for building control systems by combining a collection of linguistic control rules that were acquired from knowledgeable human operators. A fuzzy set is the result of every rule in a Mamdani system. Ebrahim Mamdani first introduced this technique in 1975. Fuzzy logic makes it possible to translate an input to an output, which serves as the fundamental building block for making judgments and identifying patterns. The parameters of the Mamdani fuzzy inference system are as follows:

- Fuzzifying the input variables.
- Rule evaluation.
- Aggregating the rule outputs.
- Defuzzifying.

3.1.1. Fuzzifying the input variables

It is the process of translating sharp values into the degree of membership meant for fuzzy set linguistic variables. Fuzzy Inference System Tool Box is used to create membership functions and determine the degree of membership values for each pixel's intensity fluctuation. The following equations determine the membership function.

$$P(i, j) = (1+(X_{max} - x_{11}(i, j) / Fe))^{\wedge} Fd$$

Where $P(i, j)$ = Resulting image pixel with i rows and j columns
$x_{11}(i, j)$ = Image pixel with i rows and j columns
X_{max} = Maximum gray level
Fe = Exponential Fuzzifier
Fd = Denominator Fuzzifier

Fig-1: Operational Formula.

3.1.2. Rule Assessment

The FIS editor's rule editor is used to change the fuzzy rules. The fuzzy inference system is used to check and change the applied rules. All of the input and output variables can have rules added to them using the rule editor. This toolbox allows for the creation, modification, and deletion of fuzzy rules. The following fuzzy principles apply for boosting the contrast of a grayscale image:

- IF a pixel is gray, then set it to that color. Make a pixel brighter if it is already bright. Make a pixel darker if it is already dark.
- The fuzzy rules' antecedents get the processed fuzzy inputs. Fuzzy operators (AND or OR) are used to create a single number that represents the outcome following the evaluation of the antecedent if the fuzzy rule that was derived has several antecedents.

3.1.3. Aggregating the rules outputs

The act of unifying all rule outputs is called aggregation. We take the membership functions of all rule consequents that have previously been scaled or clipped and merge them into a single fuzzy set. One fuzzy set for each output variable is the outcome of the aggregation procedure, which takes as its input a list of subsequent membership functions that have been scaled or clipped.

3.1.4. Defuzzification

It is the last phase of the fuzzy inference system of the Mamdani type. When evaluating rules, fuzzyness is employed; the fuzzy system's output is always a crisp number. Fuzzy collection is aggregated throughout the defuzzification process, and the result is a single, sharp number. Defuzzification of Centroids The fuzzy set's center of gravity, or methodpoint, is located. The center of gravity is expressed mathematically as follows:

$$COG = \frac{\int_a^b \mu A(Z) dz}{\int_a^b \mu A(Z) dz}$$

3.1.3. System of Sugeno Fuzzy Inference

The Sugeno Fuzzy inference approach is used in this work to fuse images. Since T. Takagi, M. Sugeno, and K. T. Kang employed the Sugeno fuzzy model for the first time in 1984, it is also known as the TSK fuzzy model. Because Mamdani-type FIS requires a significant amount of computing, Sugeno FIS—which has a faster processing time and also functions well with optimization and adaptive techniques—is employed to get around this problem. The output membership function of the Sugeno inference method is either constant or linear, which is the main distinction between the two techniques. Additionally, the Sugeno technique offers more flexibility and makes it easier to integrate with MATLAB's Adaptive Neuro-Fuzzy Inference System (ANFIS) tool.
The Sugeno type fuzzy model's format is Z is f(x, y) if x is A and y is B. where A and B are fuzzy sets, x, y, and z are linguistic variables, and f(x, y) is a mathematical function. The following fuzzy rules are applied by the Zero Order Sugeno fuzzy model, which is employed here: Z is k if x is A and y is B. where the constant is k. In this scenario, every fuzzy rule produces a constant output, and every membership function is represented by a singleton spike.

3.1.4.1. Fuzzification of inputs and membership function computation:

Pixel values in the incoming grayscale photos range from 0-255 (256 gray values). These gray values are separated into the following five membership functions' fuzzy set (B, C, G, I, and W): C stands for charcoal, G for grey, I for ivory, and W for white. The generated image has 256 gray levels and makes use of the same fuzzy set. Because it has less computing cost than other membership functions like Gaussian, Trapezoidal, etc., the triangle membership function is used in the creation of the FIS.

3.1.4.2. Uncertain rules:

The 'if-then' rules of the Sugeno type fuzzy model have W1 as the input picture, W2 as the input image, and O as the output. Consequently, there are 25 rules in all.

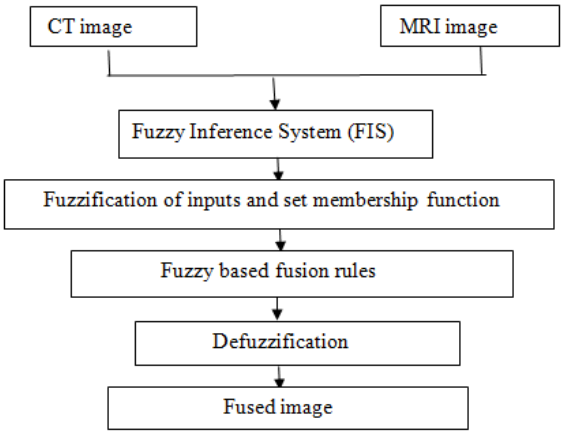

Fig-2: Table of Contents for Sugeno Fuzzy Logic.

3.1.4.3. Defuszification

The process of converting truth values into output is called defuzzification. For defuzzification, we employ the weighted average, or "water." The FIS file output is a single column matrix that needs to be transformed into an image matrix in order to produce the fused output picture.

W2 \ W1	B	C	G	I	W
B	B	C	C	G	I
C	C	B	G	I	I
G	C	C	G	I	W
I	C	G	I	I	W
W	I	G	I	W	W

Table-1: Matrix-based fuzzy rules.

4. RESULTS

This section provides insights on how simulations utilizing methods like Mamdani and Sugeno are performed on whole different sets of medical pictures. Two distinct modality pictures are used during the experiments. There are six distinct input sets, with two distinct brain pictures in each set. Fusion is carried out on every set using Sugeno rules, Sugeno extension, Mamdani rules, and Mamdani rules. Three distinct sets of CT and MRI pictures, an MR and MRA set, a PET and MRA set, and an XRAY and VA set are among the six sets of input images.When the two photos are combined into one, a wealth of information is provided that aids in more accurate diagnosis. Every image has the same 256 by 256 pixel dimensions and 256 grayscale levels. A presentation of the suggested algorithms' overall performance is made. The above figures and tables present the complete results expressed in terms of subjective and objective standards. The algorithms developed in this study are tested on a personal computer running MATLAB 8.1, equipped with an Intel(R), Core (TM), i7 CPU operating at 2.6 GHz, eight gigabytes of RAM, and 64-bit device configuration.

Subjective Analysis:
The output pictures, which display the fused images that are the result of applying the Mamdani rules, Mamdani extension, Sugeno rules, and Sugeno extension, may be visually analyzed.
Objective Analysis:
Quantitative analysis of the fused pictures utilizing well-known metrics, such as Entropy,, Edge-based quality measure, and Mutual Information ,is utilized in objective comparison to better analyze the necessary information from images.
Entropy (EN):
Entropy measures how much information there is. Better fusion is implied by higher entropy [13, 14]. The formula for calculating entropy is
EN=-∑_(t=0)^(L-1)−(P_f (i)log2P_f (i)),
where P_f is the fused image's normalized histogram and L is the greatest gray level for a pixel.
Mutual Information (MI):
This type of information reveals how dependent two variables are on one another. Assuming that A and B are

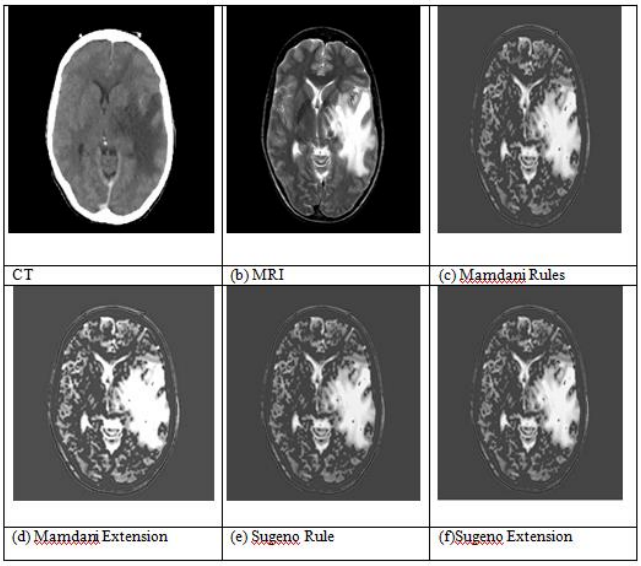

Fig-3: Fusion CT and MRI-set 1 picture.

The set 1 CT and MRI image fusion findings. The CT input picture is picture(a), while the MRI input image is Image(b). The fused pictures from the Mamdani rules are shown in Image(c), while the fused images from the Mamdani extension method are shown in Image(d). It is clear from pictures (c) and (d) that the fused image produced by Mamdani rules is inferior to the image generated by Mamdani extension. The fused image obtained from the Sugeno extension method is Image(f), while the fused image obtained from the Sugeno rules is Image(e). It has been demonstrated by the photos (e) and (f) that the fused image produced by the Sugeno extension is significantly superior to the output image produced by the Sugeno rules. Four output photos are compared, and it is evident that the fused images from Sugeno FIS have higher quality and resolution than those from Mamdani FIS.

DATASET	METHOD	ENTROPY (E)	MUTUAL INFORMATION (MI)	EDGE BASED QUALITY METRIC ($Q^{AB/F}$)
CT-MRI	Mamdani Rules	6.0781	0.2481	0.1554
	Mamdani Extension	6.0781	0.1831	0.1208
	Sugeno Rules	6.0781	0.2481	0.1554
	Sugeno Extension	6.0781	0.2369	0.1198

Table-2: CT and MRI-set Objective Metrics

Table 2 above lists the objective measures for the set 1 CT and MRI images. Here, calculations are made for entropy, mutual information, and edge-based quality metrics. The entropy values for Mamdani and Sugeno are same. In contrast to Mamdani FIS, Sugeno FIS improvises Mutual Information values. Mamdani and Sugeno rules both have the same Edge Based Quality Metric values, yet Mamdani has higher (QAB/F) values than Sugeno.

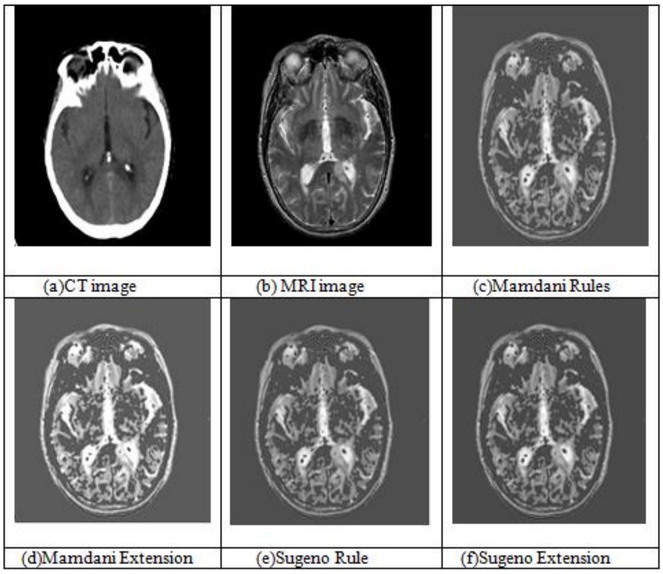

Fig-4: Combined CT and MRI Images-set 2

The fusion results of set two CT and MRI images are displayed in Figure 4. The CT input picture is picture (a), while the MRI input image is Image (b). The fused pictures from the Mamdani rules are shown in Image(c), while the fused images from the Mamdani extension method are shown in Image (d). It is obvious from pictures (c) and (d) that the fused image produced by Mamdani rules is substantially less clear than the one generated by Mamdani extension. The fused image obtained from the Sugeno extension method is Image (f), while the fused image obtained from the Sugeno rules is Image(e). It has been demonstrated by the photos (e) and (f) that the fused image produced by the Sugeno extension is significantly superior to the output image produced by the Sugeno rules.

DATASET	METHOD	ENTROPY (E)	MUTUAL INFORMATION (MI)	EDGE BASED QUALITY METRIC($Q^{AB/F}$)
CT-MRI	MamdaniRules	5.9550	0.1838	0.1860
	MamdaniExtension	5.9550	0.0968	0.1790
	Sugeno Rules	5.9550	0.1838	0.1860
	Sugeno Extension	5.9550	0.2170	0.1548

Table-3: MRI and CT Objective Metrics-set 2

Table 1 above lists the objective metrics for the second batch of CT and MRI images. Here, calculations are made for entropy, mutual information, and edge-based quality metrics. The entropy values for Mamdani and Sugeno are same. In contrast to Mamdani FIS, Sugeno FIS improvises Mutual Information values. Mamdani and Sugeno rules both have the same Edge Based Quality Metric values, yet Mamdani has higher (QAB/F) values than Sugeno.

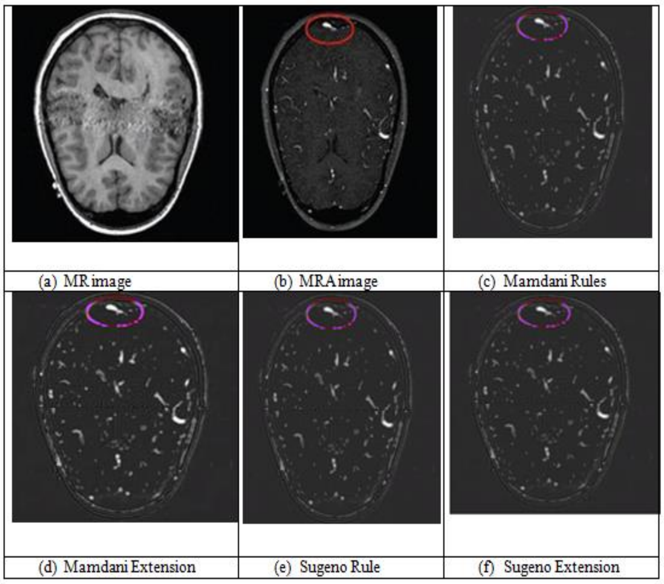

Fig-5: Combining MR and MRA Images

The fusion findings of MR and MRA images are displayed in Figure 4. The MR input picture is picture (a), while the MRA input image is Image (b). The fused pictures from the Mamdani rules are shown in Image(c), while the fused images from the Mamdani extension method are shown in Image (d). It is obvious from pictures (c) and (d) that the fused image produced by Mamdani rules is substantially less clear than the one generated by Mamdani extension. The fused image obtained from the Sugeno extension method is Image (f), while the fused image obtained from the Sugeno rules is

Image (e). It has been demonstrated by the photos (e) and (f) that the fused image produced by the Sugeno extension is significantly superior to the output image produced by the Sugeno rules.

DATASET	METHOD	ENTROPY (E)	MUTUAL INFORMATION(MI)	EDGE BASED QUALITY METRIC ($Q^{AB/F}$)
MR-MRA	Mamdani Rules	12.3002	0.0673	0.0984
	Mamdani Extension	12.3002	0.1024	0.0963
	Sugeno Rules	12.3002	0.0673	0.0984
	Sugeno Extension	12.3002	0.0648	0.0787

The table 4 above lists the objective criteria for MR and MRA pictures. Here, the quality measure based on edges, mutual information, and entropy are computed. Both Mamdani and Sugeno have the same entropy values. Sugeno FIS improvises Mutual Information values in contrast to Mamdani FIS. Mamdani and Sugeno rules both have the same Edge Based Quality Metric values, yet Mamdani's (QAB/F) values are higher than Sugeno's.

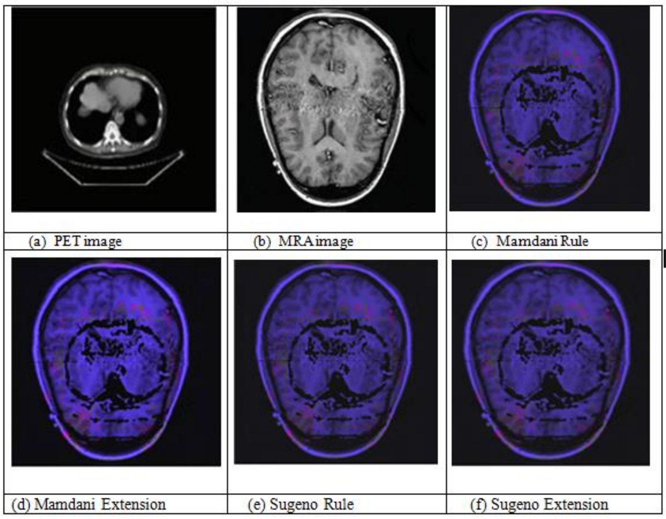

Fig-6: Combined PET and MRA Images

The fusion findings of PET and MRA images are displayed in Figure 6. The PET input picture is picture (a), while the MRA input image is Image (b). The fused pictures from the Mamdani rules are shown in Image(c), while the fused images from the Mamdani extension method are shown in Image (d). It is obvious from pictures (c) and (d) that the fused image produced by Mamdani rules is substantially less clear than the one generated by Mamdani extension. The fused image obtained from the Sugeno extension method is Image (f), while the fused image obtained from the Sugeno rules is Image (e). It has been demonstrated by the photos (e) and (f) that the fused image produced by the Sugeno extension is significantly superior to the output image produced by the Sugeno rules.

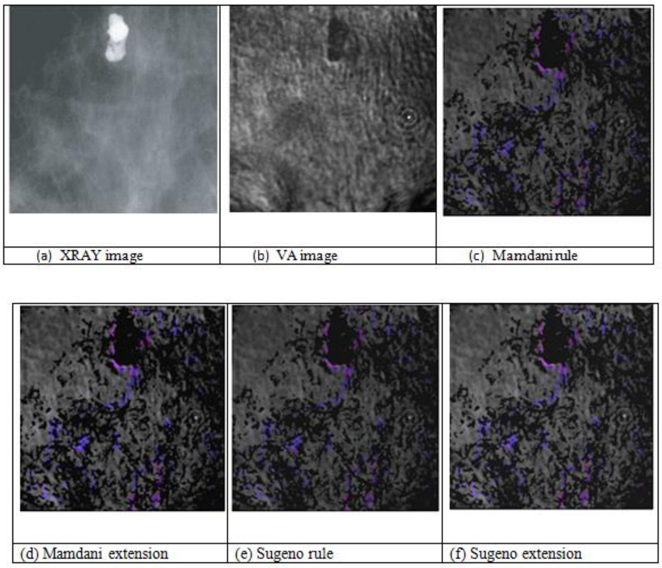

Fig-7: Combined PET and MRA Images

The combined XRAY and VA image findings are displayed in Figure 7. The input image for XRAY is Image (a), while the input image for VA is Image (b). The fused pictures from the Mamdani rules are shown in Image(c), while the fused images from the Mamdani extension method are shown in Image (d). It is obvious from pictures (c) and (d) that the fused image produced by Mamdani rules is substantially less clear than the one generated by Mamdani extension. The fused image obtained from the Sugeno extension method is Image (f), while the fused image obtained from the Sugeno rules is Image (e). It has been demonstrated by the photos (e) and (f) that the fused image produced by the Sugeno extension is significantly superior to the output image produced by the Sugeno rules.

DATASET	METHOD	ENTROPY (E)	MUTUAL INFORMATION (MI)	EDGE BASED QUALITY METRIC ($Q^{AB/F}$)
XRAY-VA	Mamdani Rules	4.7424	0.4271	0.1557
	Mamdani extension	4.7424	0.2756	0.1620
	Sugeno Rules	4.7424	0.4271	0.1557
	Sugeno Extension	4.7424	0.2519	0.1632

Table-5: Objective VA and XRAY Metrics

The table 4 above lists the objective metrics for both VA and XRAY pictures. Here, the quality measure based on edges, mutual information, and entropy are computed. Both Mamdani and Sugeno have the same entropy values. Sugeno FIS improvises Mutual Information values in contrast to Mamdani FIS. The Edge Based Quality Metric values for Sugeno and Mamdani rules are the same, while Mamdani's (QAB/F) values are higher than Sugeno's.

5. Conclusion

There is real value in these kinds of applications, and medical picture fusion is a very important method. There are several ways to do this, and in order to choose the best approach for a dedicated area, they must be computed. For doctors who need to fuse multi-modality pictures for ongoing analysis, our objective is expected to be crucial.

The fusion approach will be included into a distributed application. If the doctors had access to the Internet, they might communicate in this manner from distant places, and a report would be generated specifically for this purpose. Therefore, doctors can do image fusion from home or from their place of medical practice. We hope to incorporate further fusion techniques in the near future and test it on many supplementary medical picture types. Additionally, we wish to broaden the techniques for picture registration from many medical modalities. This study suggests approaches for picture fusion based on Mamdani and Sugeno fuzzy logic. Mamdani rule, Mamdani Extension, Sugeno rules, and Sugeno Extension are some of these techniques. The suggested techniques are significantly less computationally demanding than Mamdani FIS and are also more straightforward than exhaustive wavelet-based image fusion techniques like DWT, RDWT, and DTCWT. The suggested technique has been applied to merge several pairings of brain scans, including MR and MRA, PET and MRA, XRAY and VA, and CT and MRI pictures.

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