Multimodality Medical Image Fusion

by:

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Outlines

- Introduction
- Problem definition
- Thesis objectives
- Literature review and related work
- Proposed methods
- Experimental results
- Conclusion
- Future work

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Introduction

- Medical image is a window to the human body.
- Medical images is an essential tools in determining a medical diagnosis and treatment.
- Medical images are often affected by noise, blurriness and suffer from lack of contrast which sometimes results in false diagnosis.
- Main target in medical imaging field is to process a medical image so that the result is more suitable than the original image for a medical diagnosis.
- This is achieved by applying different efficient approaches.

Medical Image Applications

- Medical Image Fusion
- Medical Image Retrieval
- Medical Image Compression
- Tumor Detection and Mammograms
- Medical Image Filtering and Denoising

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Problem Definition

- Improving the quality of the medical image and reducing randomness and redundancy to increase the clinical applicability of medical image for diagnosis and assessment of medical problems.

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Thesis Objectives

- Presenting a survey study of medical image fusion techniques and medical imaging modalities.
- Proposing an efficient medical image fusion techniques for getting better image fusion results.
- Comparison between the proposed methods and the existing methods.

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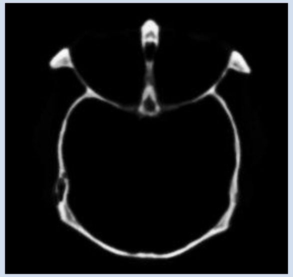
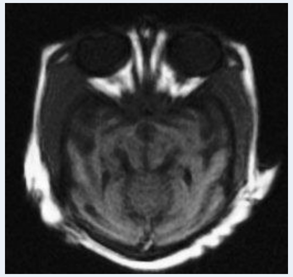
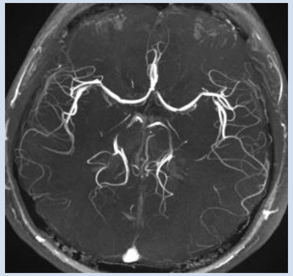
Medical Image Fusion

- Medical image fusion is the process of combining multiple images from single or multiple imaging modalities of the same organ.
  - To improve the image quality
  - To reduce redundancy
  - To increase the clinical applicability for diagnosis and assessment of medical problems

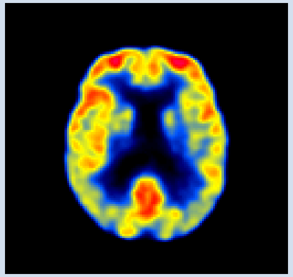
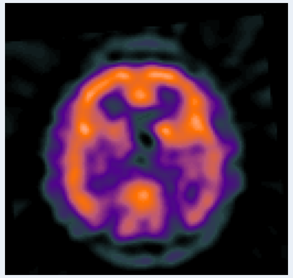
Medical Image Modalities

- Computerized Tomography (CT)
- Magnetic Resonance Imaging (MRI)
- Magnetic Resonance Angiography (MRA)
- Positron Emission Tomography (PET)
- Single-Photon Emission Computed Tomography (SPECT)

Medical Image Modalities

Modal	Advantages	Disadvantages
CT 	• Better image resolutions • Better definition of bone structure	• Tissue description is limited
MRI 	• Superior definition of soft tissue • Higher resolution	• Bone do not show up on MRI scan.
MRA 	• Focuses more on the blood vessels than the tissue surrounding it.	• Tissue description is limited

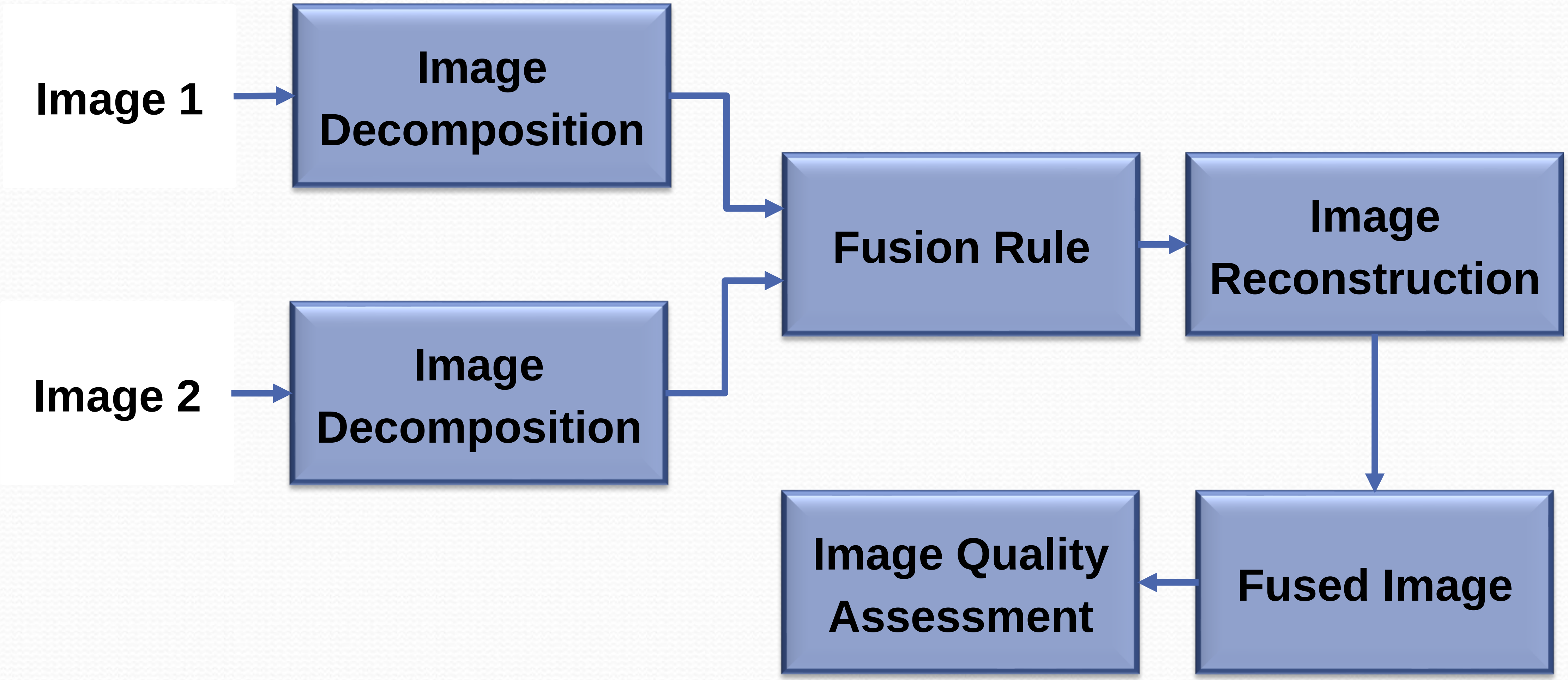
Medical Image Modalities

<table>
<tr><th>Modal</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>PET </td><td>High sensitive image
Provide functional details</td><td rowspan="2">Low resolution images so need MRI or CT (high resolution, anatomical information) to get structure information.</td></tr>
<tr><td>SPECT </td><td>Show characteristic functional information of the structures and the tissues.</td></tr>
</table>

Why medical image fusion?

- The most commonly Medical imaging techniques are MRI, MRA, PET, CT, and SPECT.
- Every modal has its characteristics and its practical limitations
- This induces to present new fusion methods for merging information from multiple imaging modalities that seldom exist using individual modality.
- Researchers have addressed many methods for medical image fusion, and have achieved good results.
- Still, there is a scope for enhancement in the performance of the fusion schemes.

Main Steps of Medical Image Fusion



Main Steps of Medical Image Fusion

Image Decomposition

- Source images are decomposed into sub-bands by performing decomposition techniques

Main Steps of Medical Image Fusion

Fusion Rule

- Applied to merge the sub-images obtained from the source images to reconstruct the fused image.

Main Steps of Medical Image Fusion

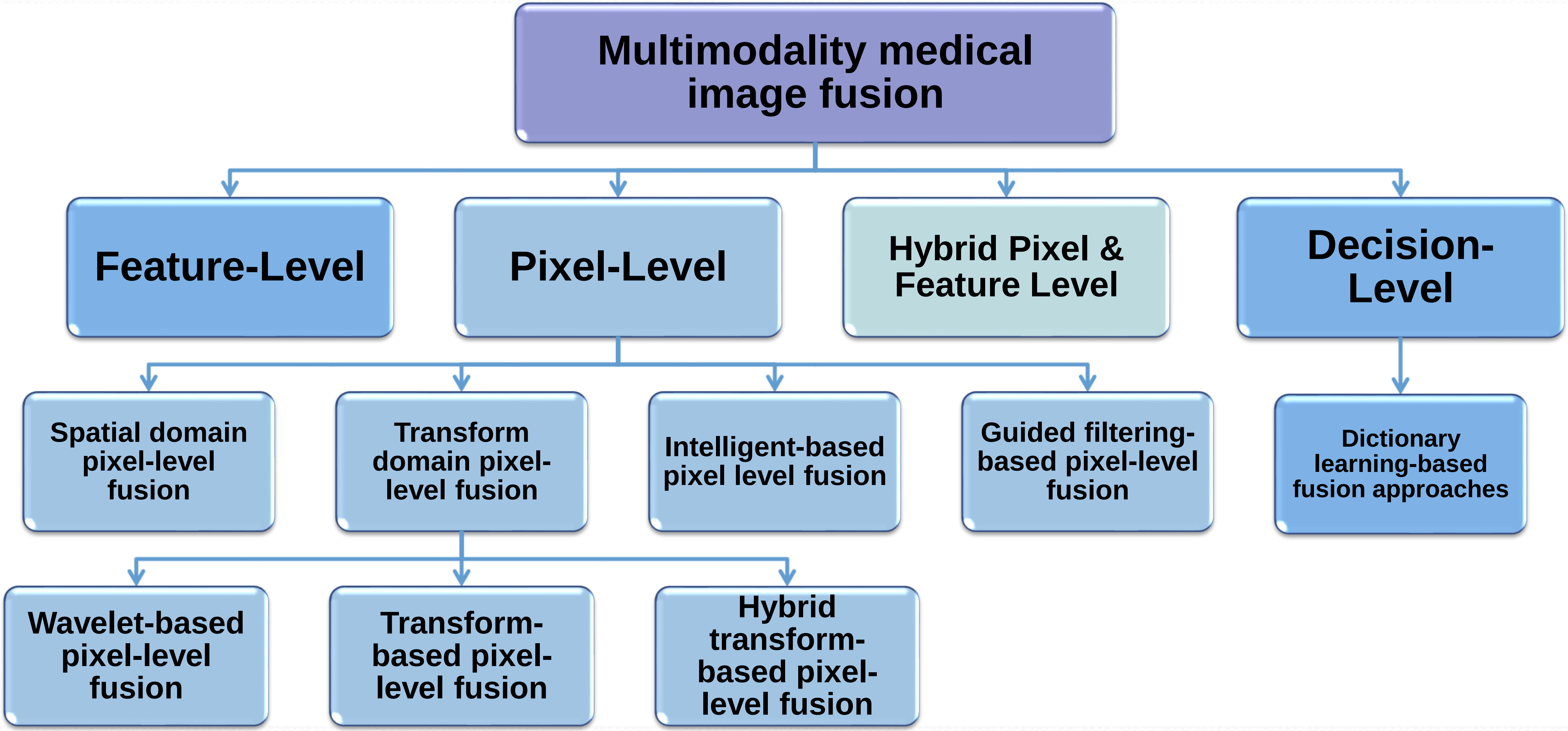
Image Reconstruction

- Implemented to obtain the final fused image using the inverse of the decomposition technique.

Main Steps of Medical Image Fusion

- Image Quality Assessment

  - Subjective Evaluation
  - Objective Evaluation


Multimodality medical image fusion
Feature-Level
Pixel-Level
Hybrid Pixel & Feature Level
Decision-Level
Spatial domain pixel-level fusion
Transform domain pixel-level fusion
Intelligent-based pixel level fusion
Guided filtering-based pixel-level fusion
Dictionary learning-based fusion approaches
Wavelet-based pixel-level fusion
Transform-based pixel-level fusion
Hybrid transform-based pixel-level fusion

Pixel-Level Fusion

- Merges original information from the source images directly or from their transforms.
- Aims to form a more informative fused image that is appropriate for visual comprehension and computer processing.
- Pixel-level fusion methods can be achieved at:
  - Spatial domain
  - Transform domain

Feature-Level Fusion

- Deals with image features since the features within an image are more valuable than individual pixels.
- In the feature-level fusion, the features are extracted separately from each source image and then the fusion method is applied based on the features from the source images.

Hybrid Pixel & Feature Level Image Fusion

- Merge the advantages of the pixel-level and the feature-level fusion approaches.
- Hybrid techniques avoid the pixel-level drawbacks such as high sensitivity to noise and blurring effects.
- Enhances the feature-level fusion methods by including the information content correlated with each pixel.

Decision-Level Fusion

- Represents a high level of fusion that indicates actual target
- Merge higher level aggregation of results from several algorithms

Advantages and Disadvantages of the State-of-the Art Methods

Methods	Advantages	Disadvantages
Spatial domain pixel-level fusion	• Preserve more spatial features • Low complexity	• Artifacts on boundaries • Fusion performance is quite limited. • Color distortion
Wavelet-based pixel-level fusion	• Reduce color distortion • Minimized distortion of the spectral information	• Cannot represent curves and edges well.
Other Transforms-based pixel-level fusion (NSCT, Curvelet, Shearlet, etc.)	• Represent curves and edges of images.	• High complexity • More time consuming

Advantages and Disadvantages of the State of the Art Methods

Methods	Advantages	Disadvantages
Intelligent-based pixel-level fusion	• More efficient than that of traditional methods	• More time consuming
Hybrid transform-based pixel-level fusion	• Avoid weak points of the one fusion technique • Combine advantages of both transform techniques	• More time consuming • Complexity of method increases.
Guided filtering-based pixel-level fusion	• Good edge-preserving • The quality of the fused image is good for human visual perception	• More time consuming

Advantages and Disadvantages of the State of the Art Methods

Methods	Advantages	Disadvantages
Feature-Level Fusion	• Deal with image features that more valuable than individual pixel	• Fusion process at this level is hard to implement since features acquired from diverse imaging modalities may be heterogeneous.
Hybrid Pixel & Feature Level Image Fusion	• Merge advantages of pixel and feature level fusion approaches. • Avoid pixel level drawbacks	• More time consuming • Complexity of method increases.
Decision-level fusion	• It reduces redundancy and uncertain information.	• Time consuming and complexity of method increase

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Problem Solution Methodology

1st proposed approach

Based on Hybrid of pixel & feature level fusion

Image decomposition
- DWT
- Curvelet transform

Fusion rule
- PCA fusion rule
- Maximum fusion rule
- Feature level fusion

2nd proposed approach

Based on SAE and NSCT domain

Image decomposition
- NSCT

Fusion rule
- SAE feature-based choose-max fusion rule
- Maximum fusion rule

1st Proposed Method

1st Proposed Method

- Proposed method is based on a hybrid of pixel and feature level based fusion method
- Proposed method is implemented using DWT and curvelet transform.
- Different fusion rules are applied.
- different features are computed for each input image to be used in feature level fusion.

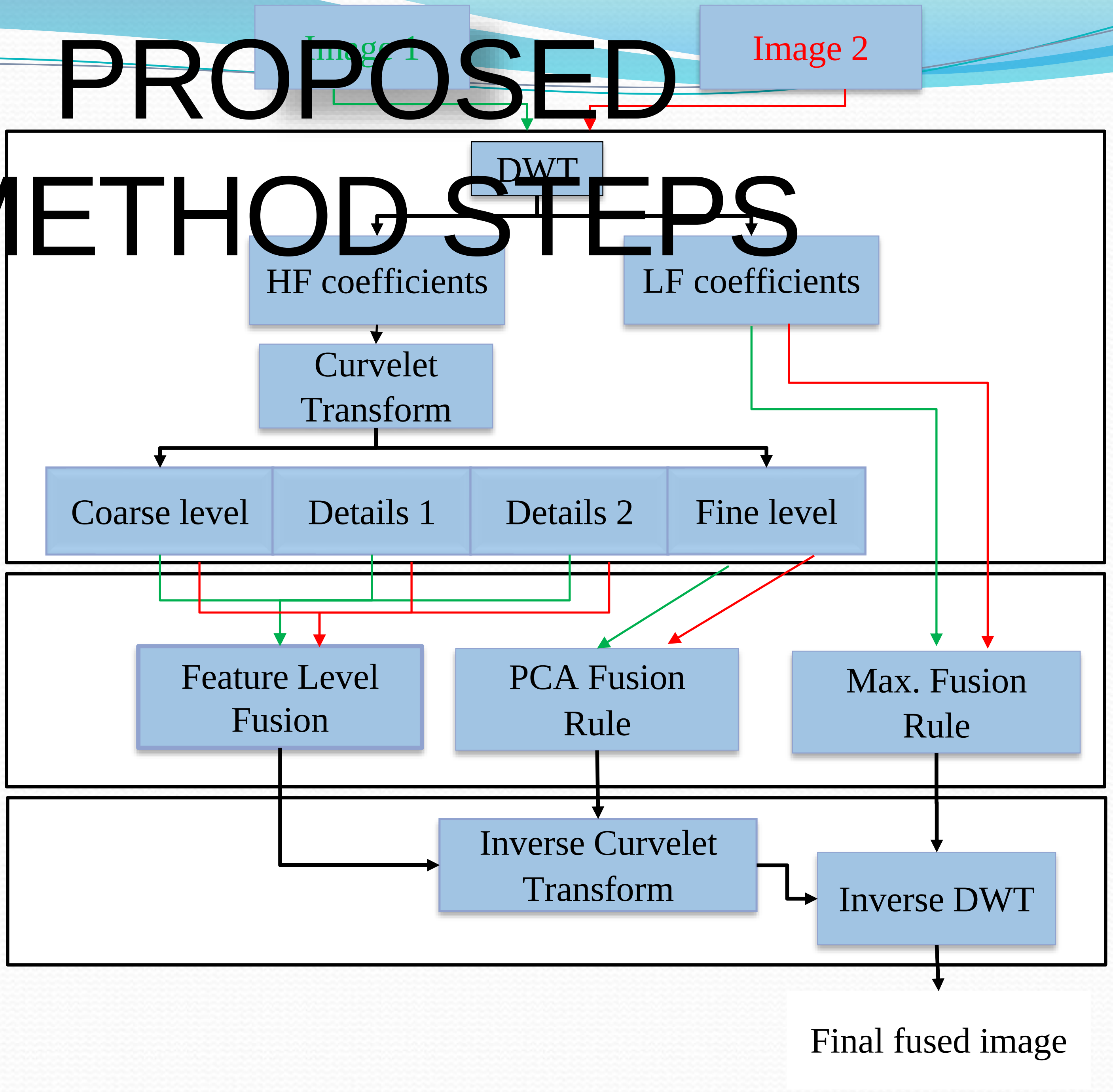
1st PROPOSED METHOD STEPS

PROPOSED METHOD STEPS

Image Decomposition

Fusion Rules

Image Reconstruction



1st Proposed Method Steps

- For each input image, DWT is applied.
- The LF coefficients of both images are fused using the maximum-based fusion rule.
- Curvelet transform used to decompose the HF coefficients of DWT into four-scale Curvelet coefficients.
- The HF sub band (fine-scale) of curvelet coefficients are fused using PCA based fusion rule.
- Other corresponding sub bands are fused based on feature level fusion.

1^{st} Proposed Method Steps

- For feature level fusion, different features (entropy, visibility, standard deviation, variance, and mean) are computed and compared.
- Inverse curvelet transform is applied.
- Inverse DWT is applied.
- Finally, fused image is assessed using different objective measures; entropy, *MI*, *SSIM*, *ESSIM*, *FSIM*, *CC*, contrast, edge intensity, *std*, and $Q^{AB/F}$.

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Datasets Description

- All the source images can be obtained at http://www.metapix.de/fusion.htm, www.imagefusion.org and www.med.harvard.edu/aanlib/home.html
- The used images are MRI, MRA, CT, PET, SPECT
- The images is 2-D gray scale and colored images with different formats
- The dimensions of images are 256*256 and 128*128
- The proposed method is evaluated on five groups of medical images include:
  - MRI, CT Images
  - MRI-T1, MRI-T2 Images
  - MRI, MRA Images
  - MRI, PET Images
  - MRI, SPECT Images

Performance Evaluation Metric Parameters

- **Mutual Information (*MI*):** measure information transfer from the source images into the final fused image.
- **Entropy:** measures the image information content. how much information is in the image.
- **Correlation Coefficient (*CC*):** Measures similarity between source images and fused image. Range 0-1
- **Structural Similarity-based Metrics (*SSIM*):** evaluates the similarity between source image and fused image range 0-1

Performance Evaluation Metric Parameters

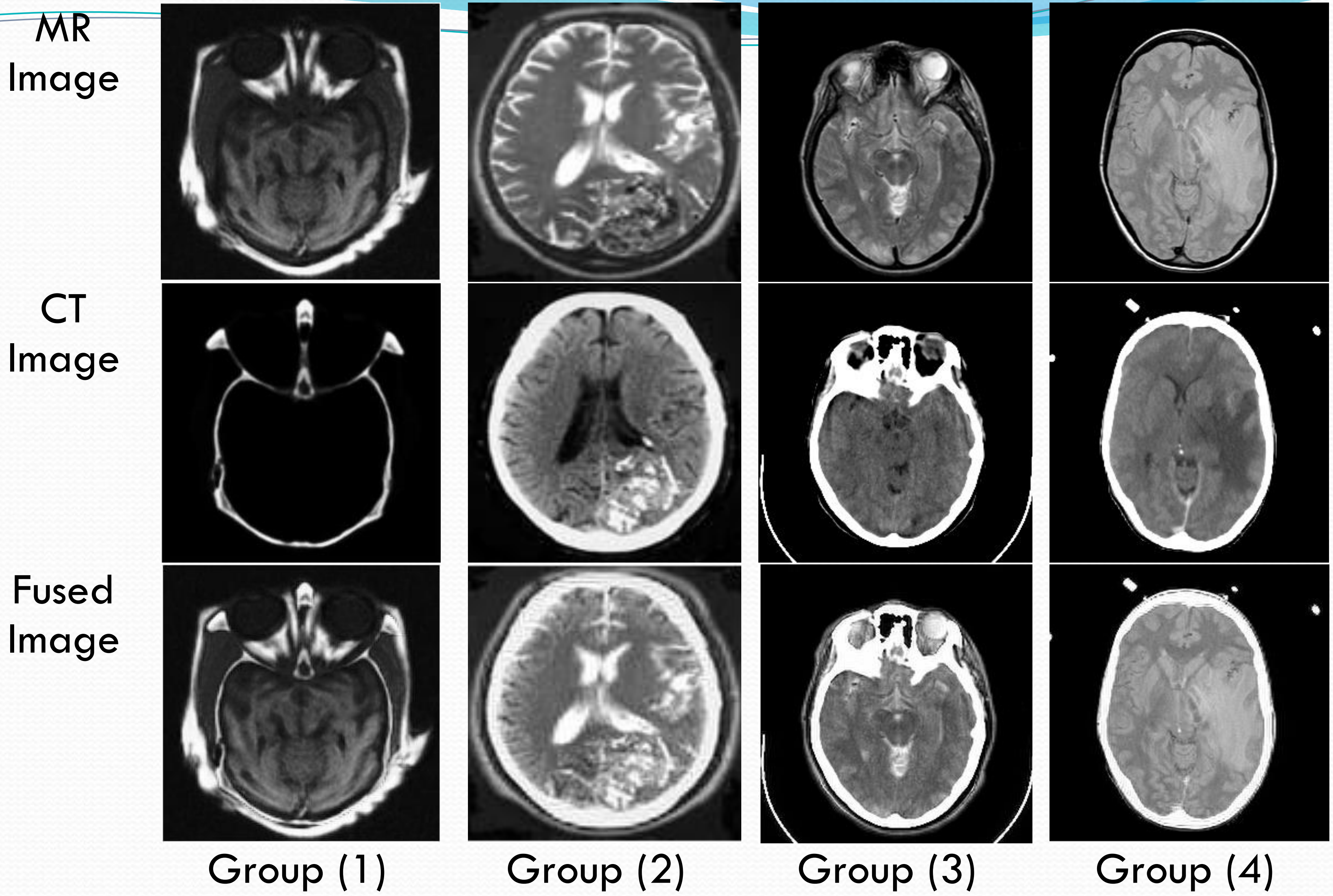
- **Feature Similarity Index (*FSIM*):** emerged from the fact that the human visual system perceives an image principally according to its low-level characteristics. Range 0-1
- **Edge-based Structural Similarity (*ESSIM*):** Compares edge information between fused image and original one. Range 0-1
- **Edge-based Similarity Measure ($Q^{AB/F}$):** Displays the amount of edge details in fused image. Range 0-1

Performance Evaluation Metric Parameters

- **Edge intensity:** A higher value of edge intensity yields an enhancement of the image quality
- **Standard deviation:** measures the data dispersion from the average value
- **Local Contrast:** evaluate the quality of the image and the clarity of the view
- **Processing Time:** the time in seconds takes to obtain the fused image

RESULTS

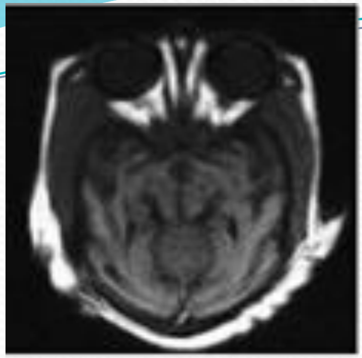
MR and CT Image Fusion Visual Assessment



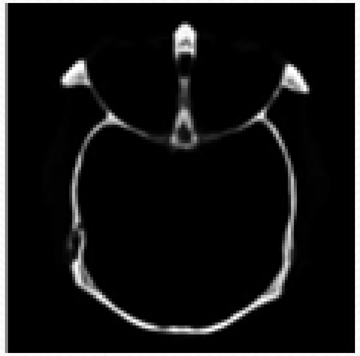
MR-CT Image Fusion
Visual Assessment

- CT image in figure shows the bone structure where the MRI image displays soft tissue information.
- The fusion method can provide better anatomical information from CT image and soft tissue information from MRI image together.
- It can be observed from figure that the proposed method preserved the main features of CT and MRI images in the fused image.

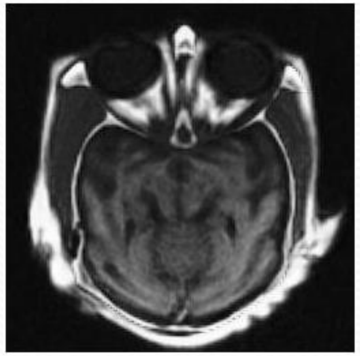
MRI



CT

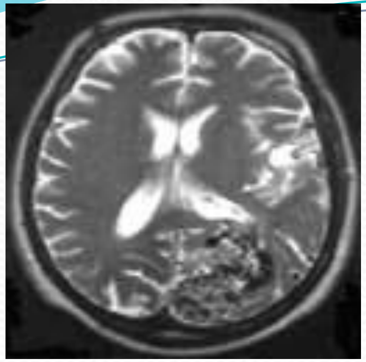


Fused Image

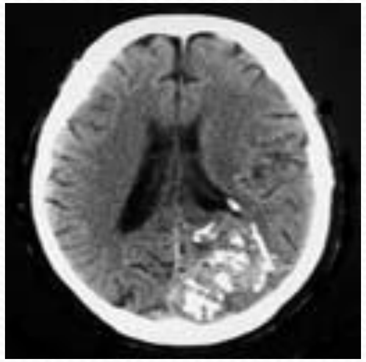


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (1)	256 × 256	CC	0.906401	0.4289	
		MI	3.8827	0.5856	
		SSIM	0.8922	0.1049	
		FSIM	0.979543	0.888971	
		ESSIM	0.999996	0.99993	
		Entropy	6.632769662	2.032499	6.7574
		$Q^{AB/F}$			0.7586
		Edge intensity			0.281595
		Contrast			0.728277
		Std			0.000947
		Variance			0.058325
		Processing	[illegible].6985 sec		

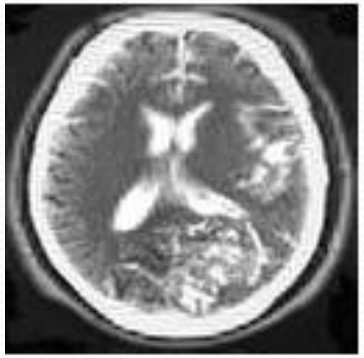
MRI



CT

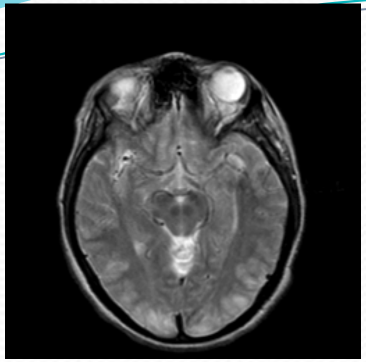


Fused Image



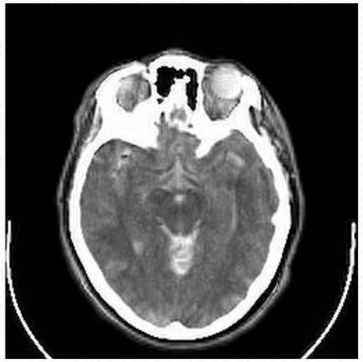
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (2)	256 × 256	CC	0.698758	0.792865	
		MI	2.785454	2.46784	
		SSIM	0.652529	0.486351	
		FSIM	0.939216	0.955559	
		ESSIM	0.999986	0.999987	
		Entropy	7.522243	7.275402	7.753463
		$Q^{AB/F}$			0.505343
		Edge intensity			0.571576
		Contrast			0.696413
		Std			0.001131
		Variance			0.083183
		Processing	1.848313 sec.		

MRI



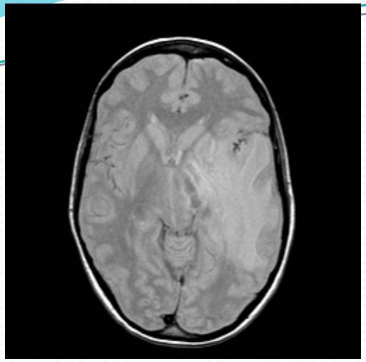
CT

Fused Image

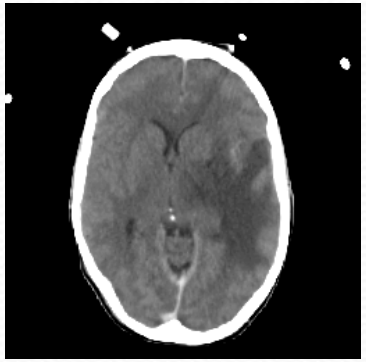


Dataset s	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (3)	256 × 256	CC	0.690143	0.931525	
		MI	1.474894	1.4261	
		SSIM	0.695076	0.763142	
		FSIM	0.930376	0.962536	
		ESSIM	0.999985	0.999991	
		Entropy	3.445887	2.677121	5.014685
		$Q^{AB/F}$			0.56828
		Edge intensity			0.340107
		Contrast			0.821052
		Std			0.001328
		Variance			0.114671
		Processing	2.379002		

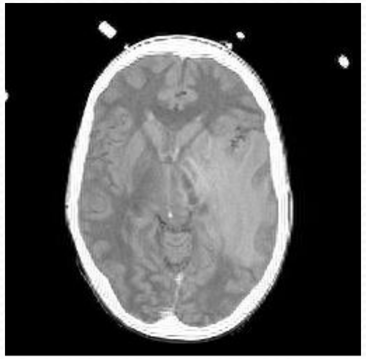
MRI



CT

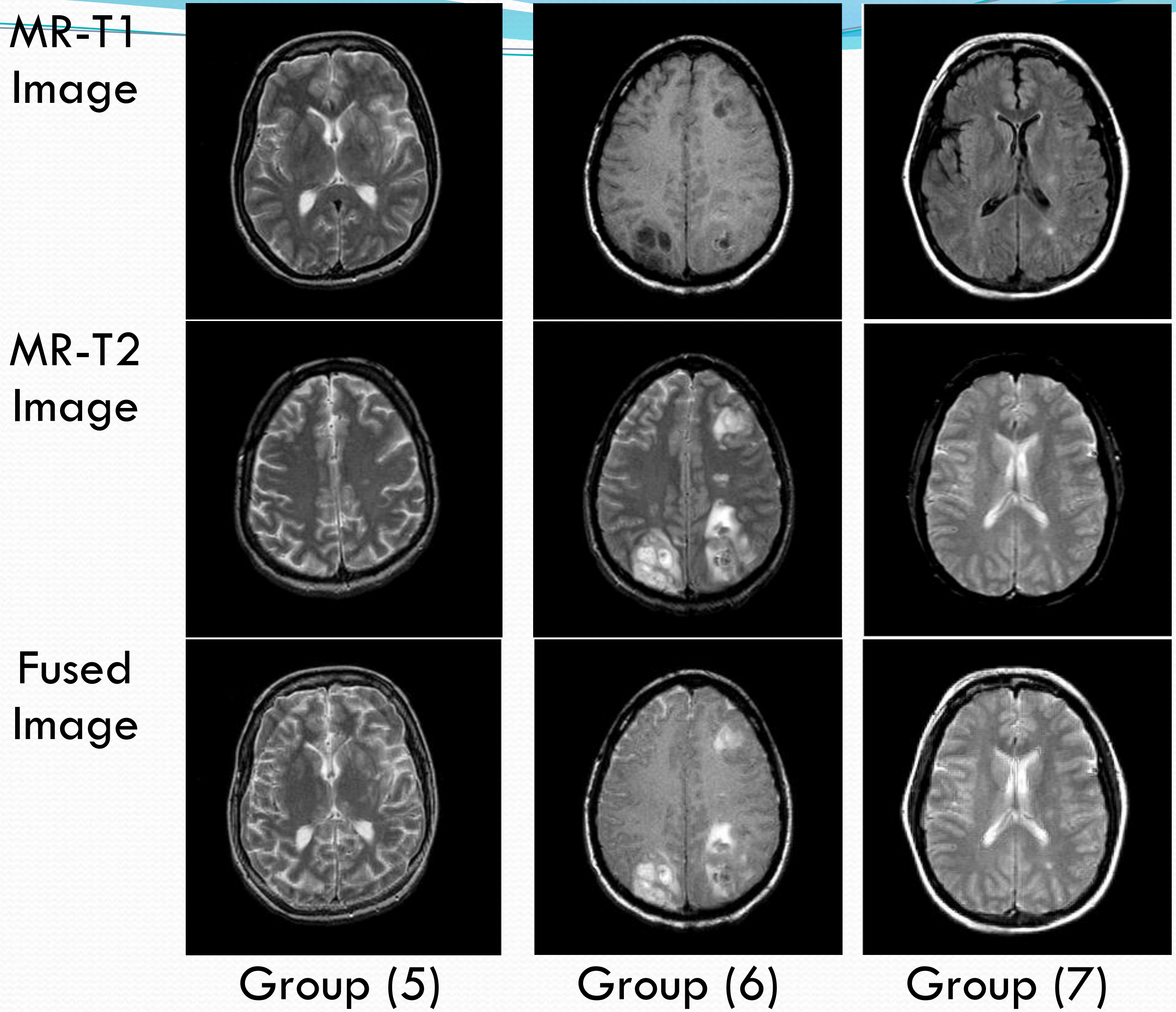


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (4)	256 × 256	CC	0.766832	0.935219	
		MI	1.923722	1.480081	
		SSIM	0.812445	0.764195	
		FSIM	0.956612	0.970772	
		ESSIM	0.999992	0.999994	
		Entropy	3.095738	2.946452	4.546677
		$Q^{AB/F}$			0.447111
		Edge intensity			0.210947
		Contrast			0.55893
		Std			0.001352
		Variance			0.118813
		Processing time	2.1727		

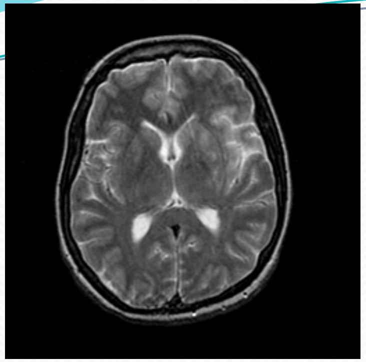
MR-T1 and MR-T2 Image Fusion Visual Assessment



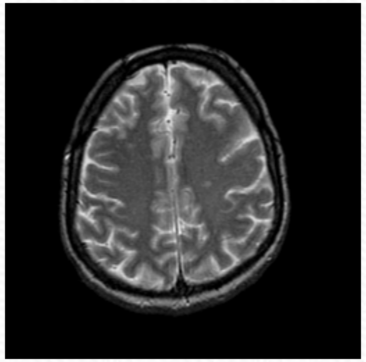
MR-T1, MR-T2 Image Fusion Visual Assessment

- MR-T1 image is the contrast modal that is the most generally utilized for brain structure analysis, but the boundaries of brain structures remain unclear in these images.
- So, fusion of these images with different sequences to reconstruct a single image with improved quality is required to obtain complementary information in a single image, so that it would be effective for clinical diagnosis.
- In the proposed method, MRI-T1 and MRI-T2 are combined to enhance the boundaries of the structure, besides improving the image quality.

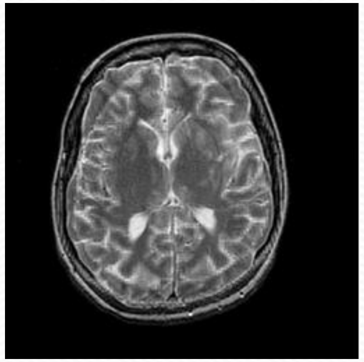
MRI-T1



MRI-T2

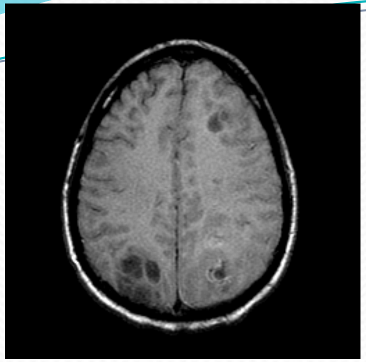


Fused Image

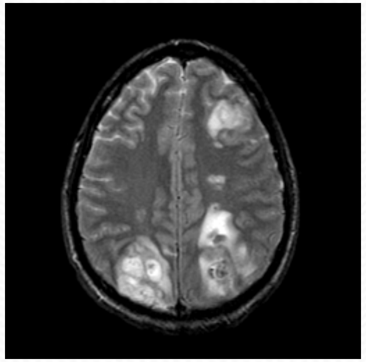


Datasets	**Size**	**Metric**	**Fused, image1**	**Fused, image2**	**Fused image**
Group (5)	256 × 256	CC	0.937902	0.847794	
		MI	4.65242	3.758753	
		SSIM	0.845206	0.731335	
		FSIM	0.96977	0.916936	
		ESSIM	0.999997	0.999991	
		Entropy	3.331931	3.080996	4.362529
		$Q^{AB/F}$			0.549182
		Edge intensity			0.266602
		Contrast			0.711696
		Std			0.000909
		Variance			0.053726
		Processing	2.180571		

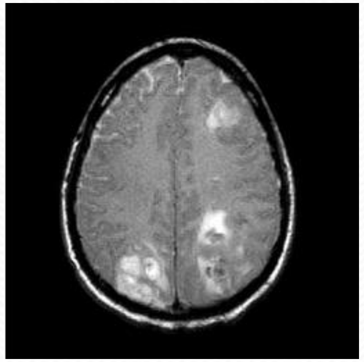
MRI-T1



MRI-T2

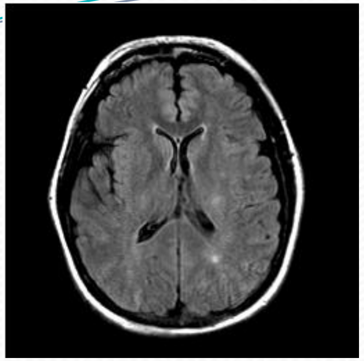


Fused Image

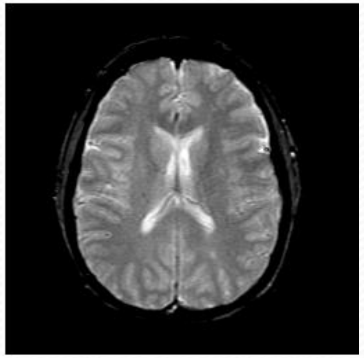


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (6)	256 × 256	CC	0.946888	0.935497	
		MI	3.056232	2.921821	
		SSIM	0.859041	0.763632	
		FSIM	0.976103	0.960401	
		ESSIM	0.999998	0.999996	
		Entropy	2.974882	3.209406	4.282903
		$Q^{AB/F}$			0.575182
		Edge intensity			0.209073
		Contrast			0.608012
		Std			0.001029
		Variance			0.0688
		Processing	6.533551		

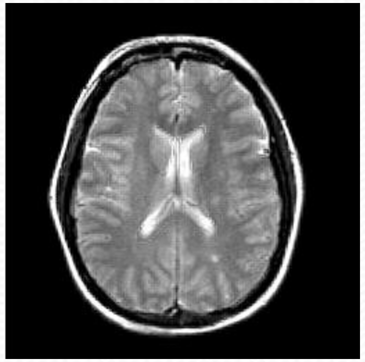
MRI-T1



MRI-T2



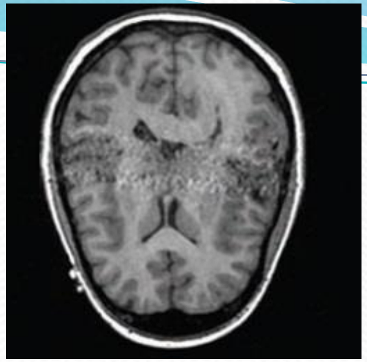
Fused Image



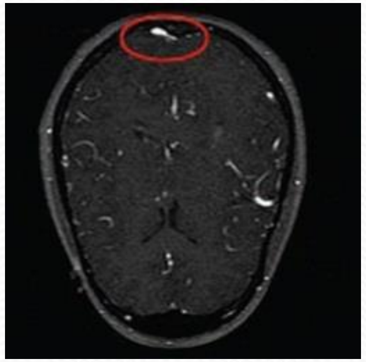
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (7)	256 × 256	CC	0.8833	0.8233	
		MI	1.4089	1.6857	
		SSIM	0.7527	0.8145	
		FSIM	0.954961	0.887828	
		ESSIM	0.999996	0.999988	
		Entropy	3.585163	3.263062	4.5464
		$Q^{AB/F}$			0.6196
		Edge intensity			0.294775
		contrast			0.673838
		Std			0.001097
		Variance			0.078236
		Processing	2.8920		

MR and MRA Image Fusion Visual Assessment

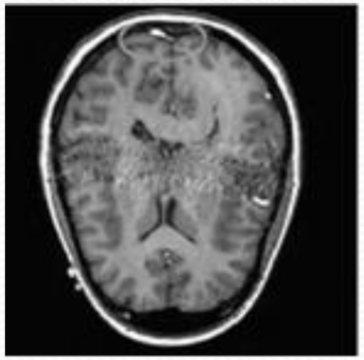
MRI-T1



MRA



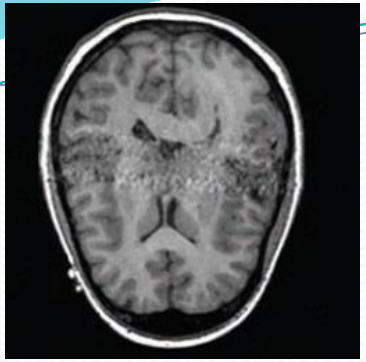
Fused Image



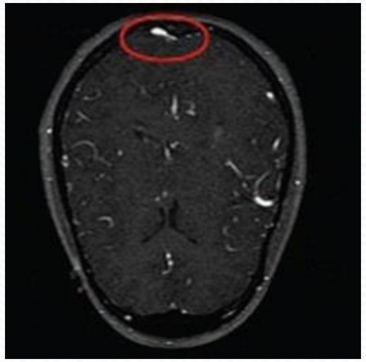
MRI-MRA Images Fusion Visual Assessment

- MRI image provides clear information for the soft tissues; however, it cannot observe the abnormality.
- MRA image can easily detect the abnormalities, it has insufficient tissues information.
- So, the fusion process of the two images with the appropriate method is essential to get a fused image with complementary information helpful in clinical diagnosis.
- As in figure the proposed method preserves the information from the source images.

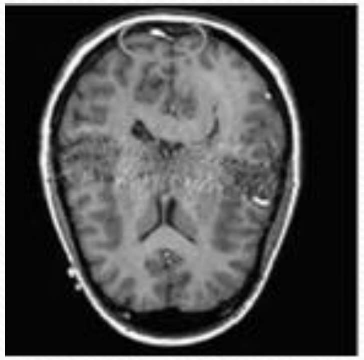
MRI-T1



MRA

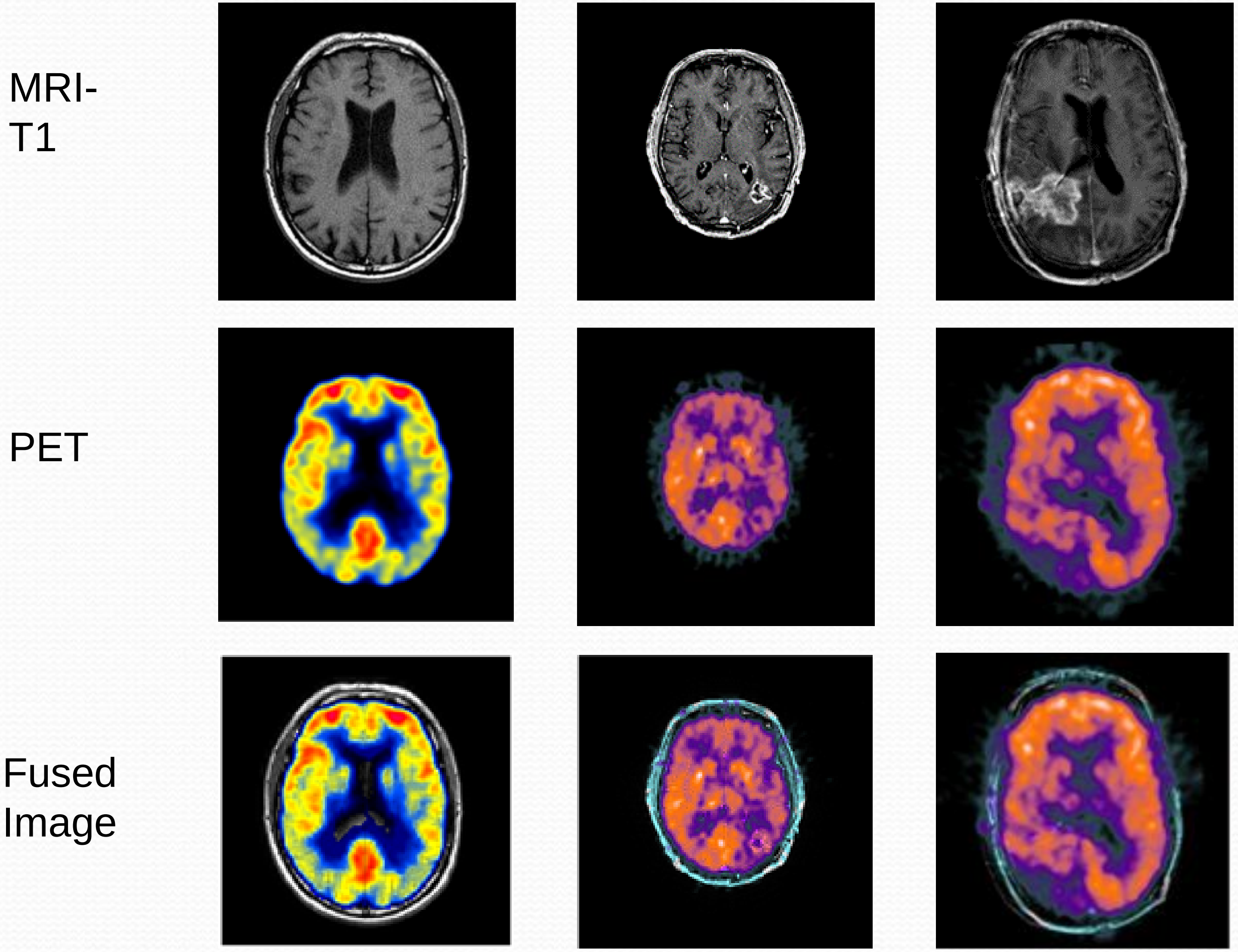


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (8)	256 × 256	CC	0.990122	0.817918	
		MI	3.6747	1.9043	
		SSIM	0.963403	0.563003	
		FSIM	0.995296	0.937495	
		ESSIM	0.999999	0.999992	
		Entropy	5.867818	4.911601	6.02737
		$Q^{AB/F}$			0.669455
		Edge intensity			0.299096
		contrast			0.681107
		Std			0.001029
		Variance			0.068827
		Processing	2.382021		

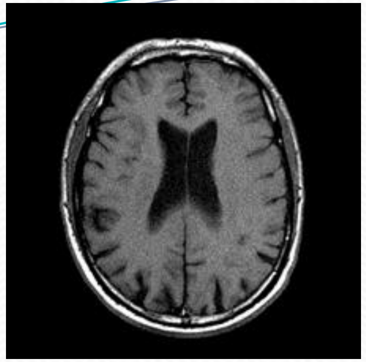
MR and PET Image Fusion Visual Assessment



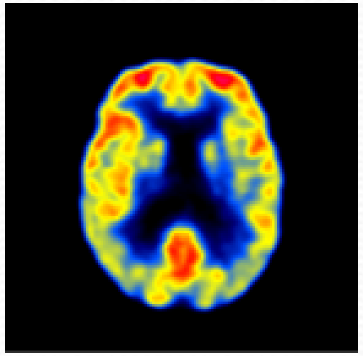
MRI-PET Images Fusion
Visual Assessment

- PET imaging modality incorporates functional data acquisition with low resolution image.
- MRI image offers a clear soft tissue image and anatomic information.
- Figure shows that the proposed method achieved a fused image that combined the complementary information of two images and the color is perfectly kept in the integrated images.

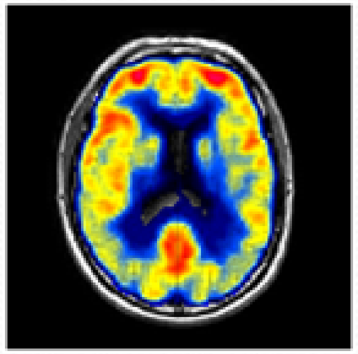
MRI-T1



PET

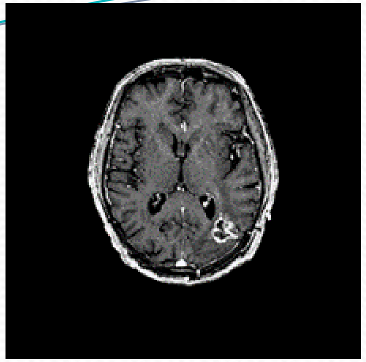


Fused Image

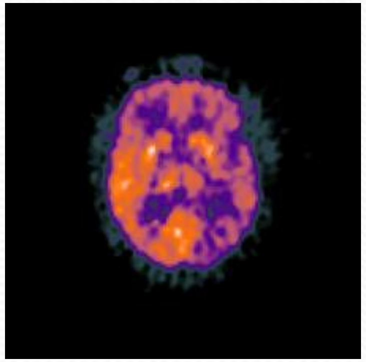


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (9)	128 × 128	CC	0.843685	0.900689	
		MI	8.436275	4.072438	
		SSIM	0.706925	0.726409	
		FSIM	0.93142	0.952352	
		ESSIM	0.999993	0.999977	
		Entropy	4.424126	2.689293	4.795067
		$Q^{AB/F}$			0.579481
		Edge intensity			0.471174
		contrast			0.886692
		Std			0.001498
		Variance			0.146016
		Processing	13.18878		

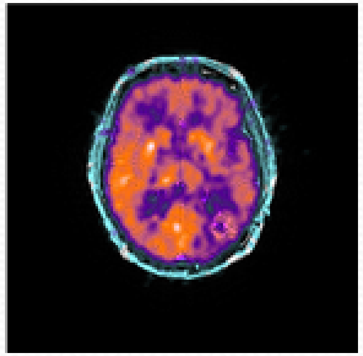
MRI-T1



PET



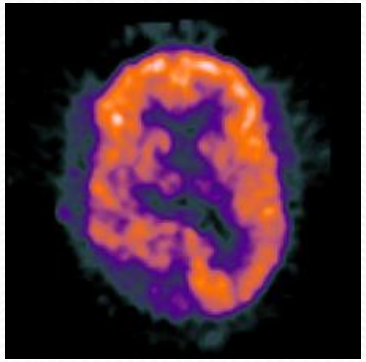
Fused Image



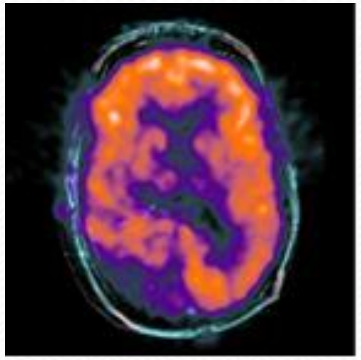
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (10)	256 × 256	CC	0.85844	0.906862	
		MI	1.059998	1.499181	
		SSIM	0.829941	0.841775	
		FSIM	0.980935	0.983548	
		ESSIM	0.999996	0.999994	
		Entropy	2.272423	2.493845	3.473756
		$Q^{AB/F}$			0.478778
		Edge intensity			0.220434
		contrast			0.75979
		Std			0.001188
		Variance			0.091728
		Processing	8.034635		

MRI-T1

PET

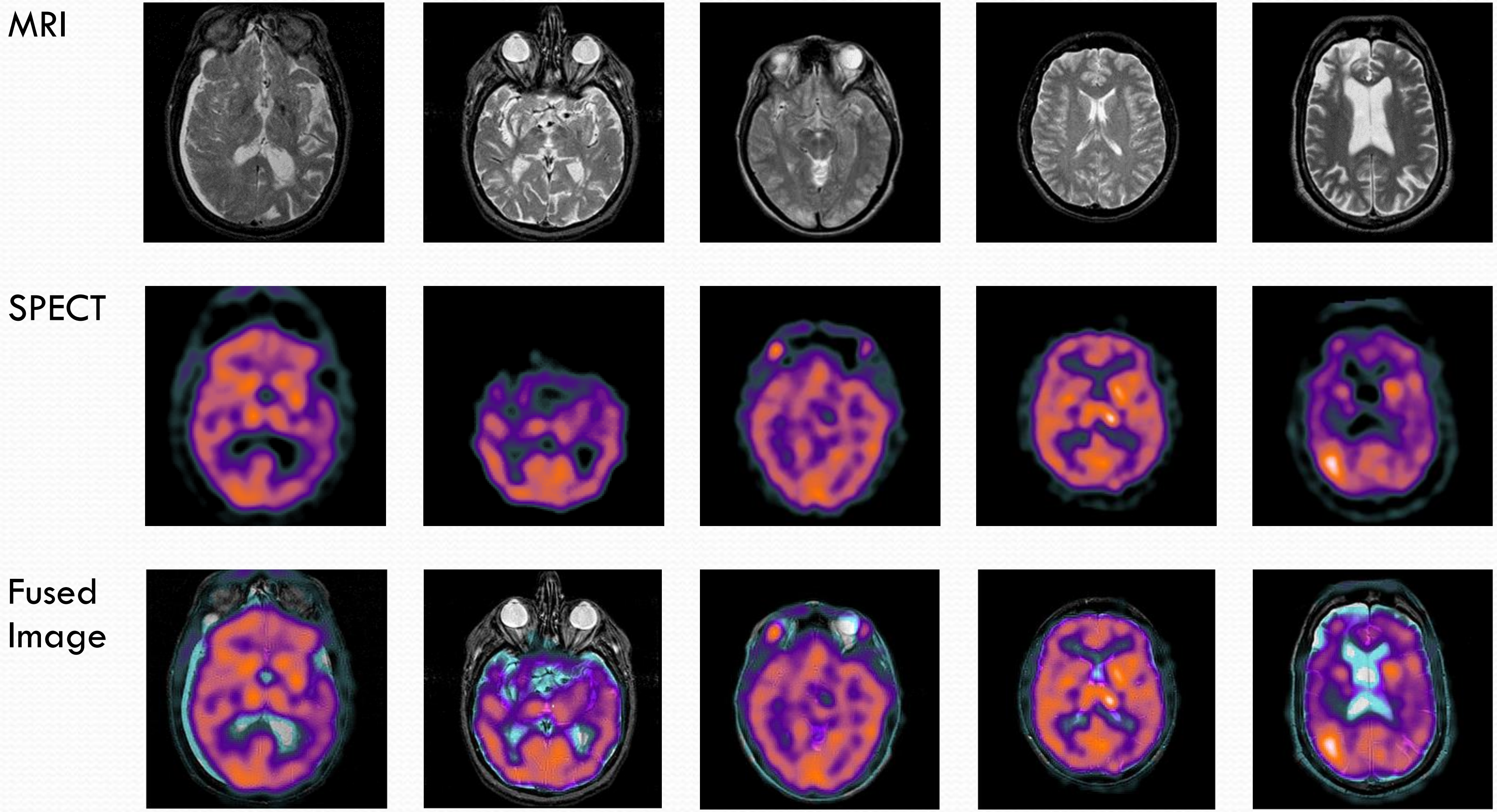


Fused Image

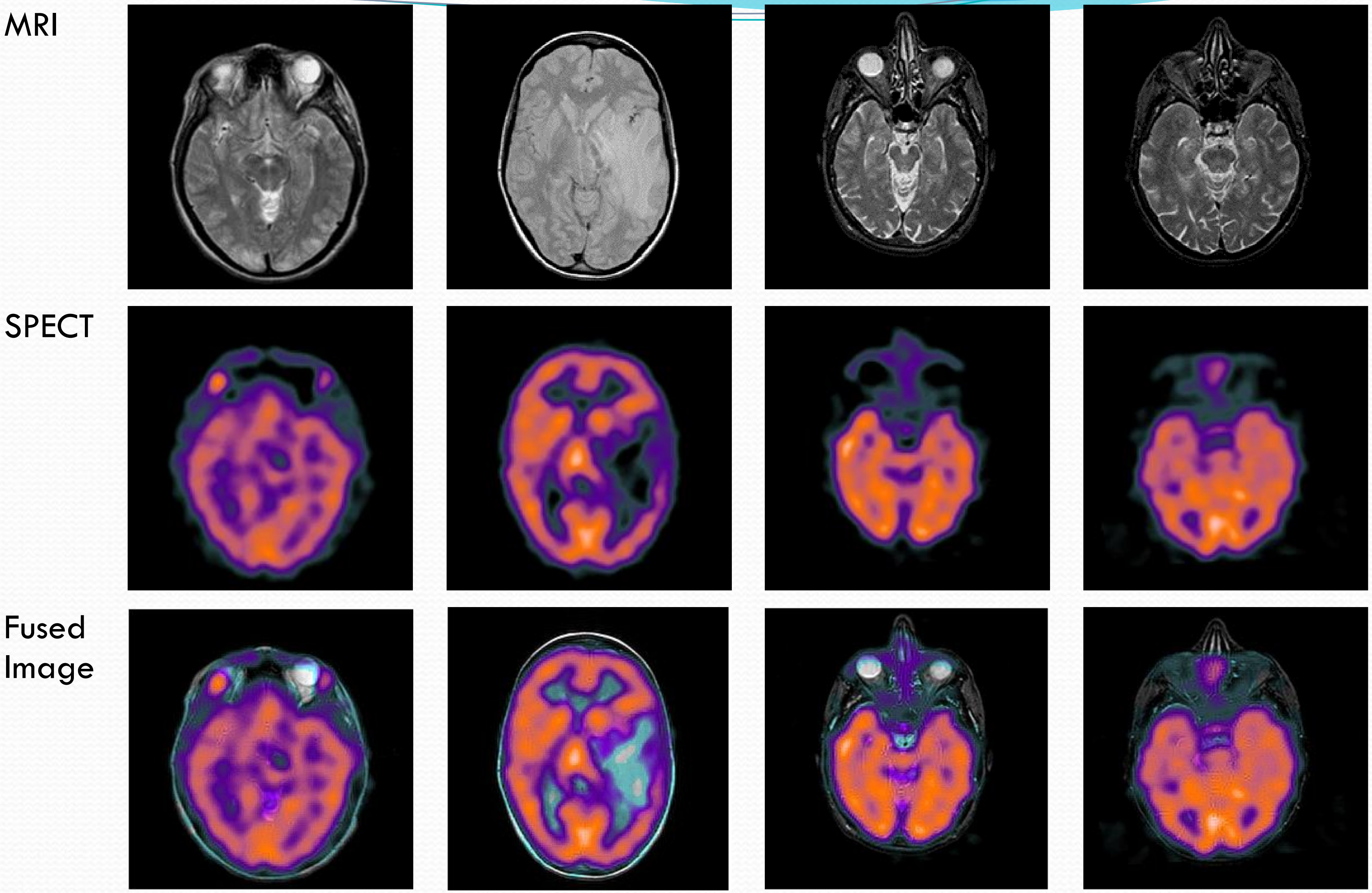


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (11)	256 × 256	CC	0.75161	0.965751	
		MI	1.308583	2.404525	
		SSIM	0.596849	0.854721	
		FSIM	0.92479	0.977752	
		ESSIM	0.999994	0.999995	
		Entropy	3.37178	4.228631	5.688478
		$Q^{AB/F}$			0.524134
		Edge intensity			0.220541
		contrast			0.548115
		Std			0.001309
		Variance			0.111504
		Processing	7.975237		

MR and SPECT Image Fusion Visual Assessment



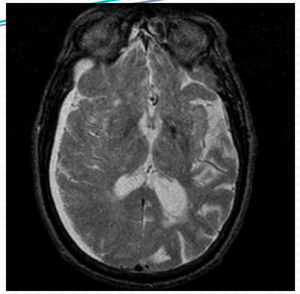
MR and SPECT Image Fusion Visual Assessment



MRI-SPECT Images Fusion
Visual Assessment

- SPECT modal provides a low-resolution color image, where MRI image is a high-resolution image with better anatomical details.
- The fused image of MRI and SPECT images should preserve all the anatomical details of the MRI image without changing the color of the SPECT image that does not alter the functional content.
- Visual analysis of SPECT-MRI fusion in figure proved that the obtained image combined the soft tissue of MRI

MRI



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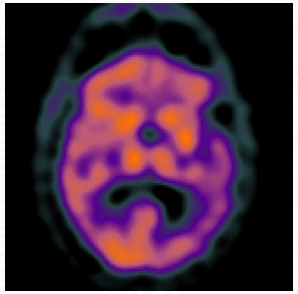
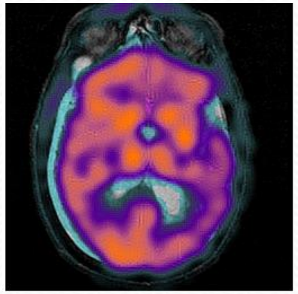
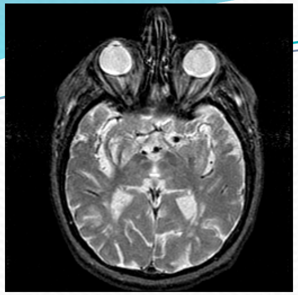


Fused
Image

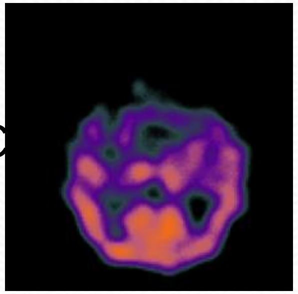


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (12)	256 × 256	CC	0.853753	0.916044	
		MI	2.973545	3.337293	
		SSIM	0.69819	0.63245	
		FSIM	0.904392	0.937319	
		ESSIM	0.999996	0.999994	
		Entropy	4.652689	4.404903	6.217953
		$Q^{AB/F}$	0.441738		
		Edge intensity	0.217781		
		contrast	0.504742		
		Std	0.001175		
		Variance	0.089842		
		Processing	8.286084		

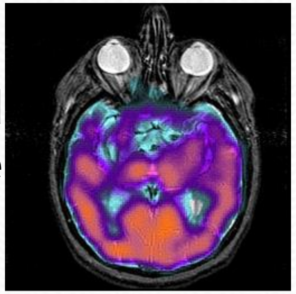
MRI



SPECT

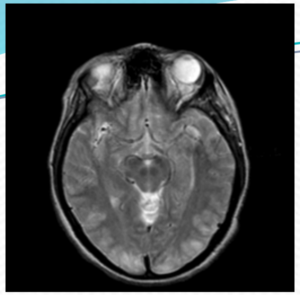


Fused Image

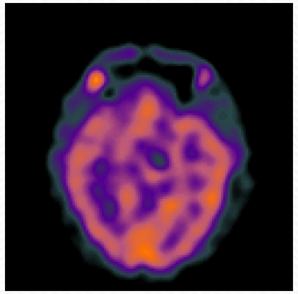


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (13)	256 × 256	CC	0.957356	0.794862	
		MI	3.903703	2.547283	
		SSIM	0.895171	0.505964	
		FSIM	0.963266	0.826461	
		ESSIM	0.999998	0.999982	
		Entropy	4.484795	2.499	5.319904
		$Q^{AB/F}$			0.679231
		Edge intensity			0.329394
		contrast			0.69599
		Std			0.001194
		Variance			0.092696
		Processing	7.98057		

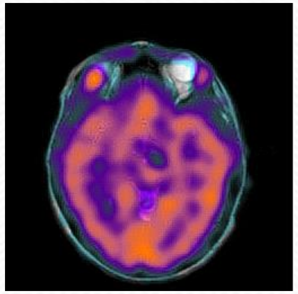
MRI



SPECT

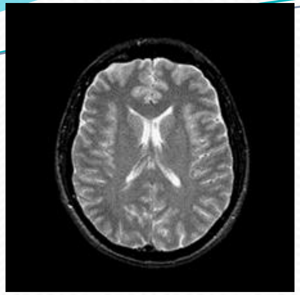


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (14)	256 × 256	CC	0.902411	0.944518	
		MI	1.449958	2.09184	
		SSIM	0.735503	0.835404	
		FSIM	0.936237	0.971887	
		ESSIM	0.999995	0.999996	
		Entropy	3.445887	3.491055	4.924513
		$Q^{AB/F}$			0.446702
		Edge intensity			0.174519
		contrast			0.506029
		Std			0.001196
		Variance			0.092997
		Processing	8.142549		

MRI



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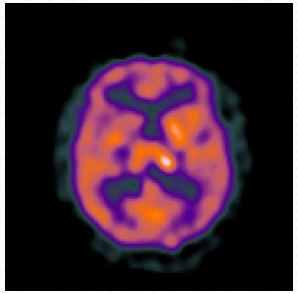
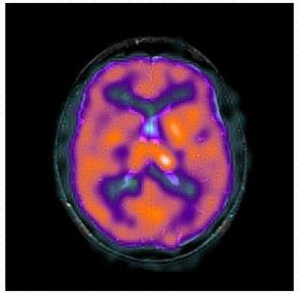
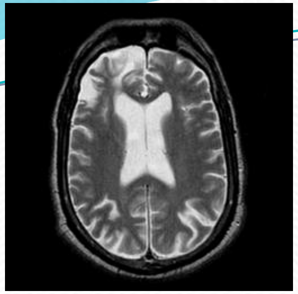


Fused
Image

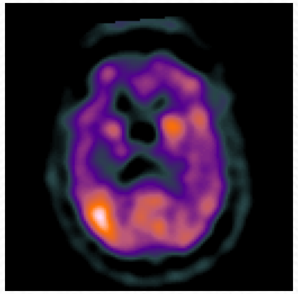


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (15)	256 × 256	CC	0.9378	0.9780	
		MI	1.3785	2.0936	
		SSIM	0.7552	0.8428	
		FSIM	0.965019	0.973798	
		ESSIM	0.99999	0.999999	
		Entropy	3.174119	3.483786	4.641986
		$Q^{AB/F}$			0.4357
		Edge intensity			0.174705
		contrast			0.546781
		Std			0.001248
		Variance			0.101301
		Processing	3.7269		

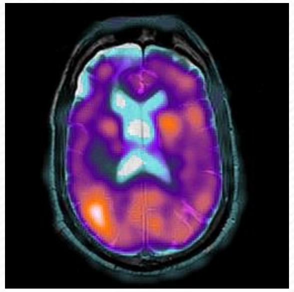
MRI



SPECT

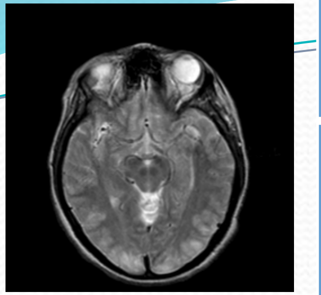


Fused Image

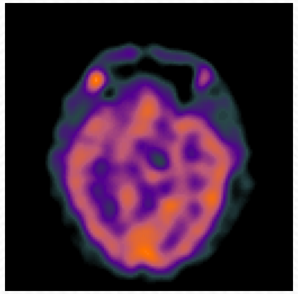


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (16)	256 × 256	CC	0.914856	0.837816	
		MI	3.468039	3.83528	
		SSIM	0.80185	0.67668	
		FSIM	0.961173	0.946837	
		ESSIM	0.999996	0.999993	
		Entropy	3.895176	3.681655	5.106712
		$Q^{AB/F}$			0.543792
		Edge intensity			0.223498
		contrast			0.558539
		Std			0.001193
		Variance			0.092564
		Processing	8.127691		

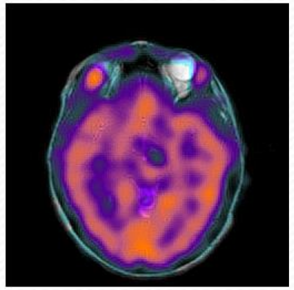
MRI



SPECT

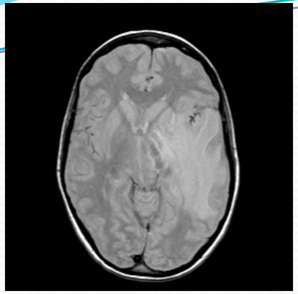


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (17)	256 × 256	CC	0.902411	0.944518	
		MI	1.449958	2.09184	
		SSIM	0.735503	0.835404	
		FSIM	0.936237	0.971887	
		ESSIM	0.999995	0.999996	
		Entropy	3.445887	3.491055	4.924513
		$Q^{AB/F}$			0.446702
		Edge intensity			0.174519
		contrast			0.506029
		Std			0.001196
		Variance			0.092997
		Processing	8.151526		

MRI



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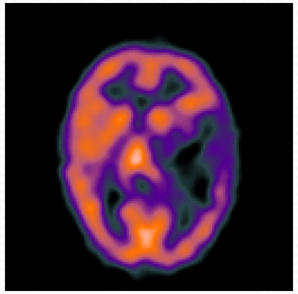
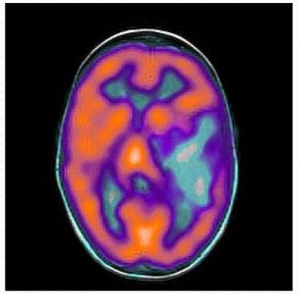
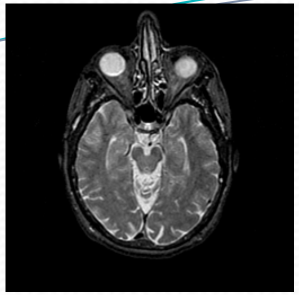


Fused
Image



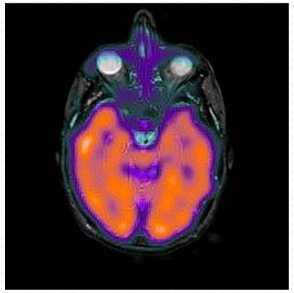
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (18)	256 × 256	CC	0.942654	0.911097	
		MI	1.459708	1.782513	
		SSIM	0.797792	0.7764	
		FSIM	0.946592	0.944504	
		ESSIM	0.999996	0.999992	
		Entropy	3.095738	3.401559	4.852009
		$Q^{AB/F}$			0.511265
		Edge intensity			0.20882
		contrast			0.518154
		Std			0.001339
		Variance			0.116548
		Processing	8.134452		

MRI



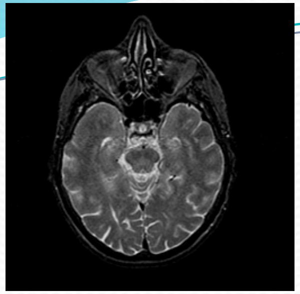
SPEC
T

Fused
Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (19)	256 × 256	CC	0.877127	0.951248	
		MI	1.607385	1.775358	
		SSIM	0.814467	0.780961	
		FSIM	0.966359	0.972946	
		ESSIM	0.999996	0.999995	
		Entropy	2.988912	2.80937	4.122755
		$Q^{AB/F}$			0.441106
		Edge intensity			0.18221
		contrast			0.627878
		Std			0.001228
		Variance			0.098131
		[illegible]	[illegible]		

MRI



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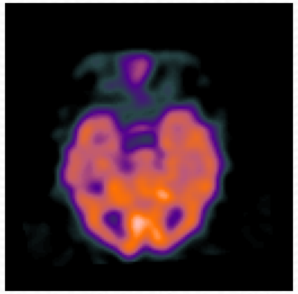
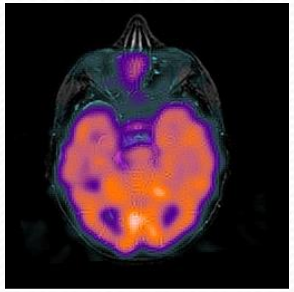


Fused
Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (20)	256 × 256	CC	0.863611	0.986506	
		MI	1.198272	1.965825	
		SSIM	0.733925	0.817587	
		FSIM	0.94916	0.969978	
		ESSIM	0.999995	0.999996	
		Entropy	3.068157	3.333017	4.667776
		$Q^{AB/F}$			0.373105
		Edge intensity			0.157978
		contrast			0.543936
		Std			0.001231
		Variance			0.098578
		[illegible]	[illegible]		

Comparison with Existing Methods

- Comparison with the existing methods in the area of medical image fusion is a difficult issue since different works have utilized different datasets for experimentation.
- Besides, various authors use different parameters to assess their performance.
- However, the results obtained by the proposed method are compared with the several recent existing fusion methods in a quantitative manner using the most

COMPARISON WITH EXISTING METHODS MRI

Methods	Metrics					
	Entropy	MI	CC	SSIM	$Q^{AB/F}$	Time
Fast curvelet tarnsform with Genetic Algorithm [9] 2020	----	3.3121	-----	0.8651	0.4262	-----
Biorthogonal WT with average and maximum fusion rule [1] 2019	6.2974	---	---	---	0.6812	---
NSST [2] 2018	6.4179	2.376	---	---	---	---
NSCT-SR-PCNN [3] 2018	---	2.2426	---	0.9567	0.6899	---
NSCT [4] 2019	---	2.2188	---	---	**0.8502**	---
SR-Modified Spatial frequency [5] 2018	---	---	---	---	0.6606	---
Intuitionistic fuzzy sets (IFS) [6] 2019	**6.806**	---	0.647	---	0.636	3.75
Deep Stacked CNN [7] 2018	6.188	3.464	---	---	---	11.046
CNN [8] 2017	---	---	---	---	---	12.1
1st Proposed method	**6.7574**	**4.4683**	**0.9064**	**0.9971**	0.7586	**2.6085**

2^{nd} Proposed Method

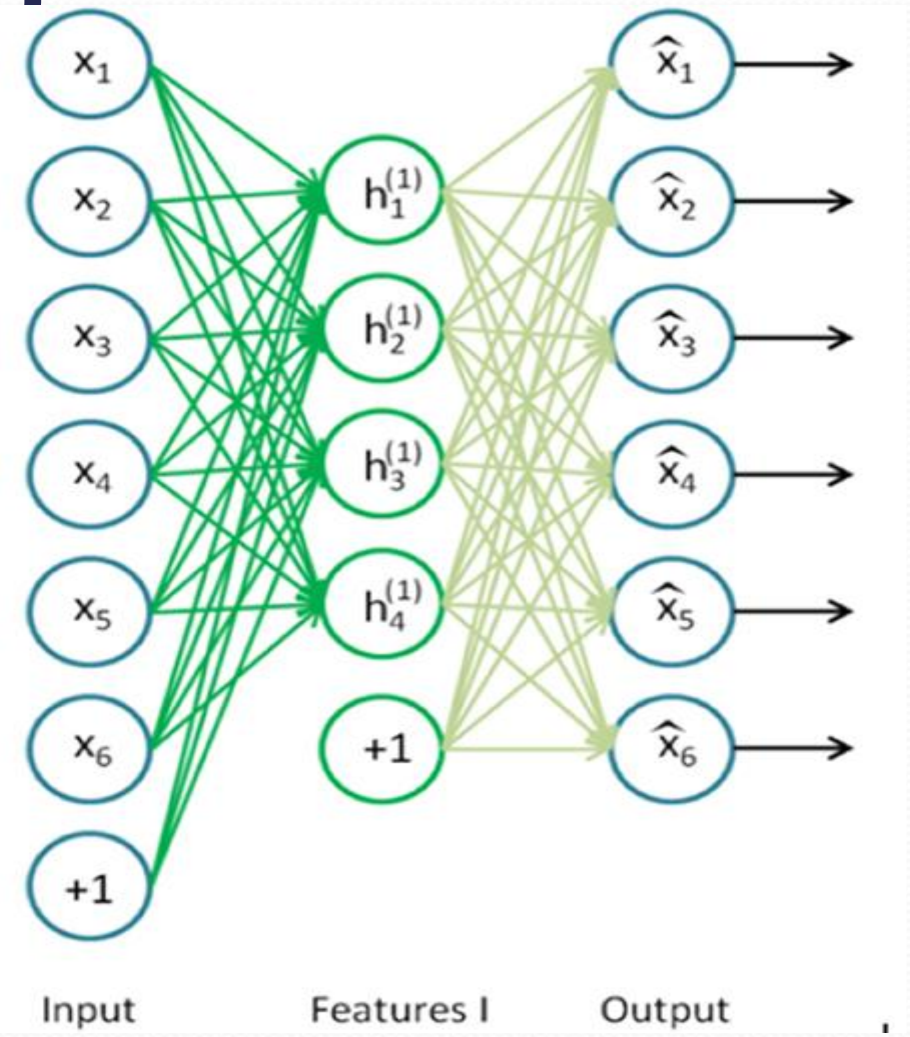
2nd Proposed Method

- Proposed method is based on a hybrid of pixel and feature level based fusion method
- Proposed method is implemented using NSCT
- Different fusion rules are applied.
- Stacked Autoencoder (SAE) is used as automatic feature extractor.
- The proposed method is assessed using different pairs of medical images

Stacked Autoencoder (SAE)

- SAE is a common class of deep neural networks
- SAE consists of multiple layers of autoencoders
- The autoencoder is trained to extract features from unlabeled data.
- The encoder map the input data into hidden representation, where the decoder is used to reconstruct input data from the hidden representation.
- The encoder process is defined as

$$h_n = f(W_1 x_n + b_1)$$



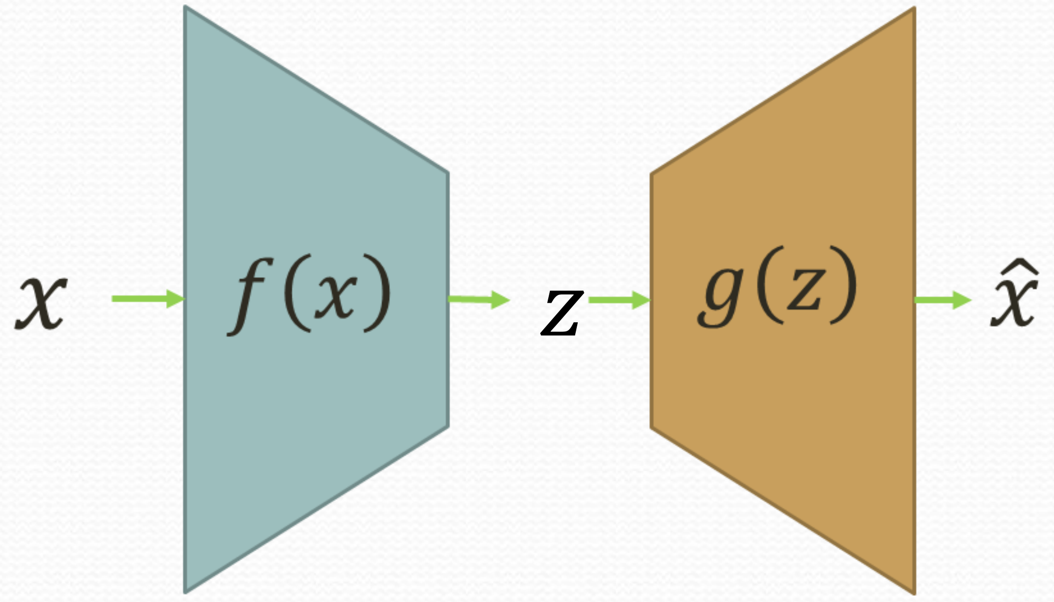
Stacked Autoencoder (SAE)

- The decoder process is defined as

$$\hat{x}_n = g(W_2 h_n + b_2)$$

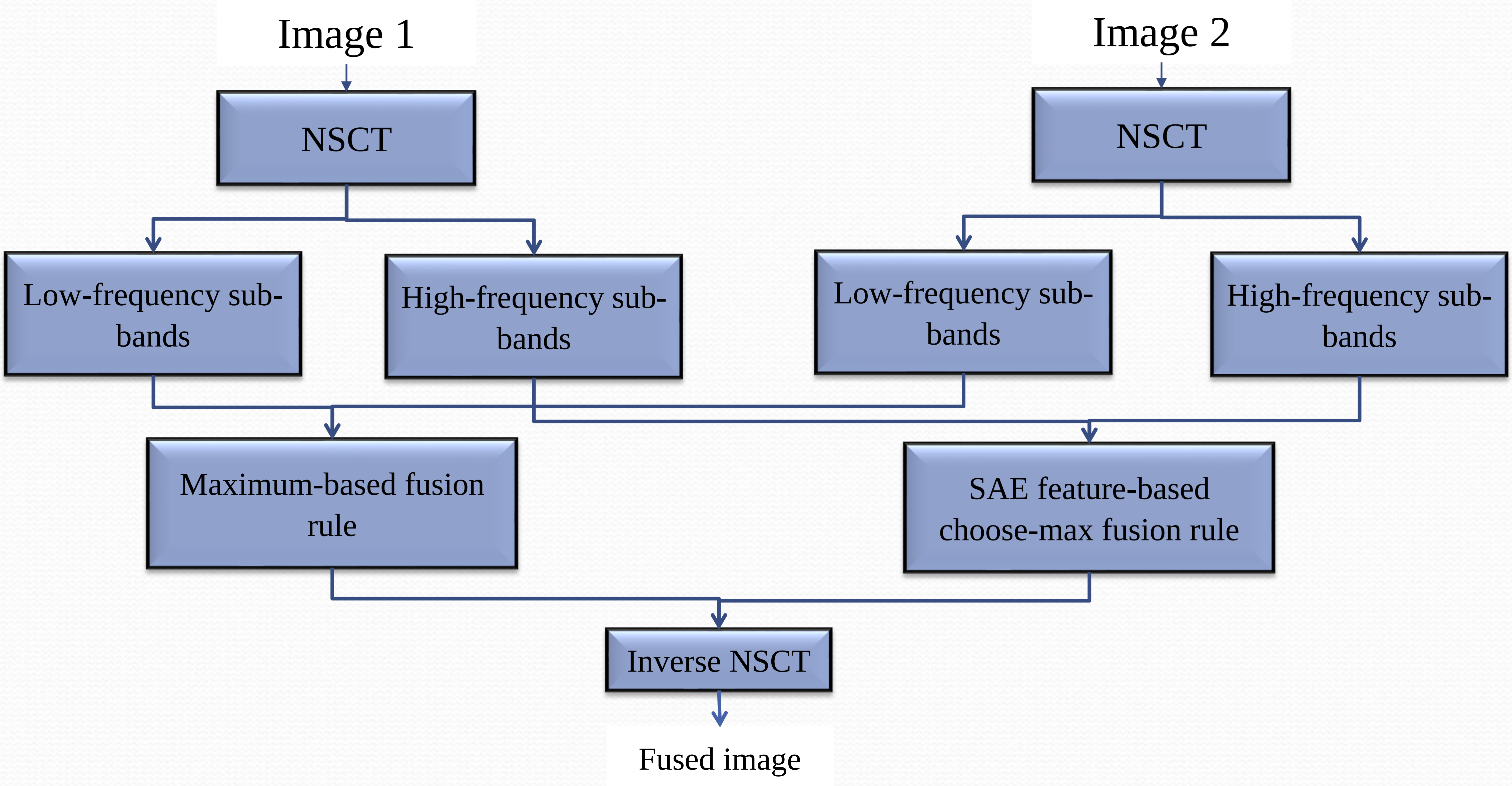
- The parameters of the autoencoder are optimized to decrease the reconstruction error:

$$\emptyset(\Theta) = arg_{\theta,\theta'} \min \frac{1}{n} \sum_{i=1}^{n} L(x^i, \hat{x}^i)$$



- where L denotes a loss function $L(x, \hat{x}) = \|x - \hat{x}\|^2$.

2nd PROPOSED METHOD STEPS



2^{nd} PROPOSED METHOD STEPS

- The input images are decomposed into low-frequency and high-frequency coefficients by using NSCT.
- Low-frequency sub-bands represent the image approximation, and these coefficients are combined by the maximum-based fusion rule.
- The high-frequency sub-bands comprise the significant details information of the images, the high-frequency sub-bands are combined by the SAE-based choose-max fusion approach.
- The final fused image is reconstructed by implementing the

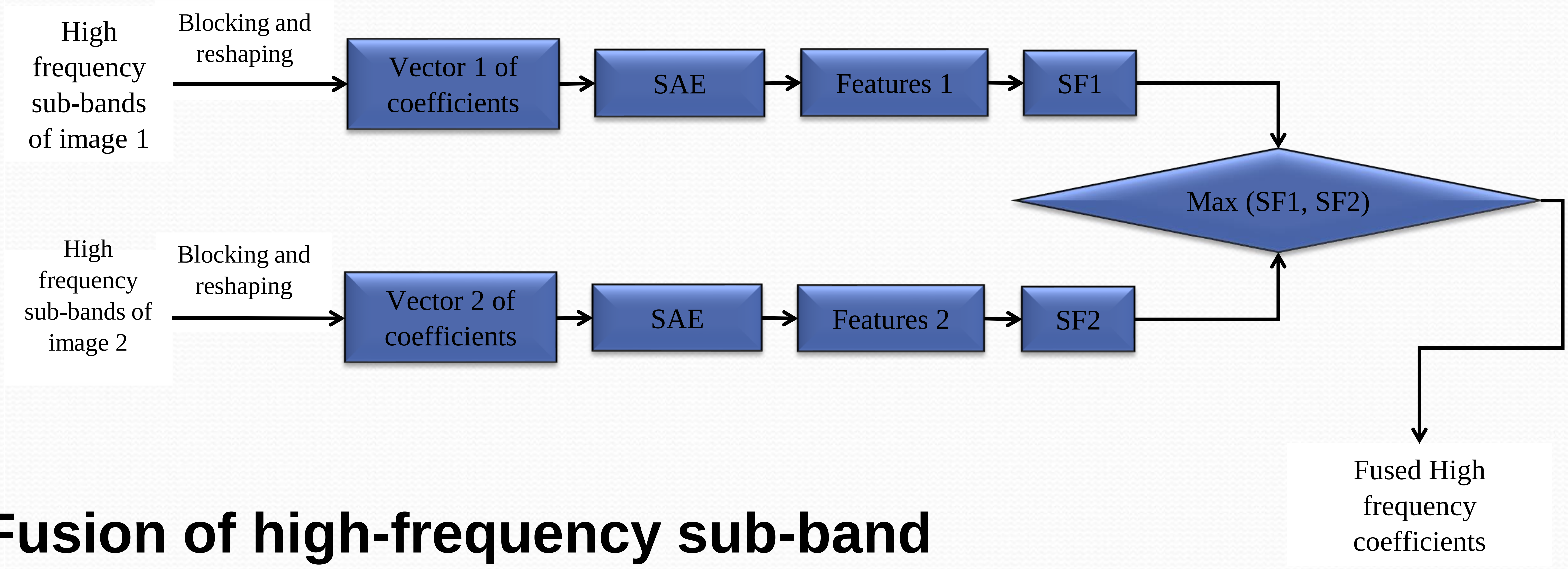
2nd PROPOSED METHOD STEPS

- **Fusion of low-frequency sub-band coefficients**
  - Maximum based fusion rule is adopted to fuse the low-frequency coefficients
  - The maximum fusion rule assists to improve the visual quality of the final fused image in terms of better contrast.

$$C_L^F(i,j) = Max(C_L^A(i,j), C_L^B(i,j))$$

- Where $C_L^A(i,j), C_L^B(i,j)$ represent low-frequency coefficients of the input images and $C_L^F(i,j)$ is the fused low-frequency coefficients.

2nd PROPOSED METHOD STEPS



Fusion of high-frequency sub-band coefficients

2^{nd} PROPOSED METHOD STEPS

Fusion of high-frequency sub-band coefficients

- High-frequency coefficients of input images are divided into blocks.
- All obtained blocks from two images are reshaped into vectors.
- The coefficients vectors are delivered as input to SAE for training, then the feature vectors are extracted.
- The spatial frequency (SF) of the feature vectors is calculated to adopt in the fusion process.

$$SF = \sqrt{RF^2 + CF^2}$$

$$RF = \sqrt{\frac{1}{M(N-1)} \sum_{i=1}^{M} \sum_{j=2}^{N} (X(i, j-1) - X(i, j))^2}$$

$$CF = \sqrt{\frac{1}{(M-1)N} \sum_{i=2}^{M} \sum_{j=1}^{N} (X(i, j) - X(i-1, j))^2}$$

2nd PROPOSED METHOD STEPS

Fusion of high-frequency sub-band coefficients

- For each pair of coefficients vectors, select the one with maximum SF as the fused vector if:

$$C_H^F(i,j) = \begin{Bmatrix} C_H^A(i,j), & if\ \left(SF_H^A \geq SF_H^B\right) \\ C_H^B(i,j), & if\ \left(SF_H^A < SF_H^B\right) \end{Bmatrix}$$

- where C_H^A, C_H^B are the high-frequency sub-bands of the two images and C_H^F is the fused high-frequency sub-band. SF_H^A, SF_H^B are the spatial frequency of the feature vectors.

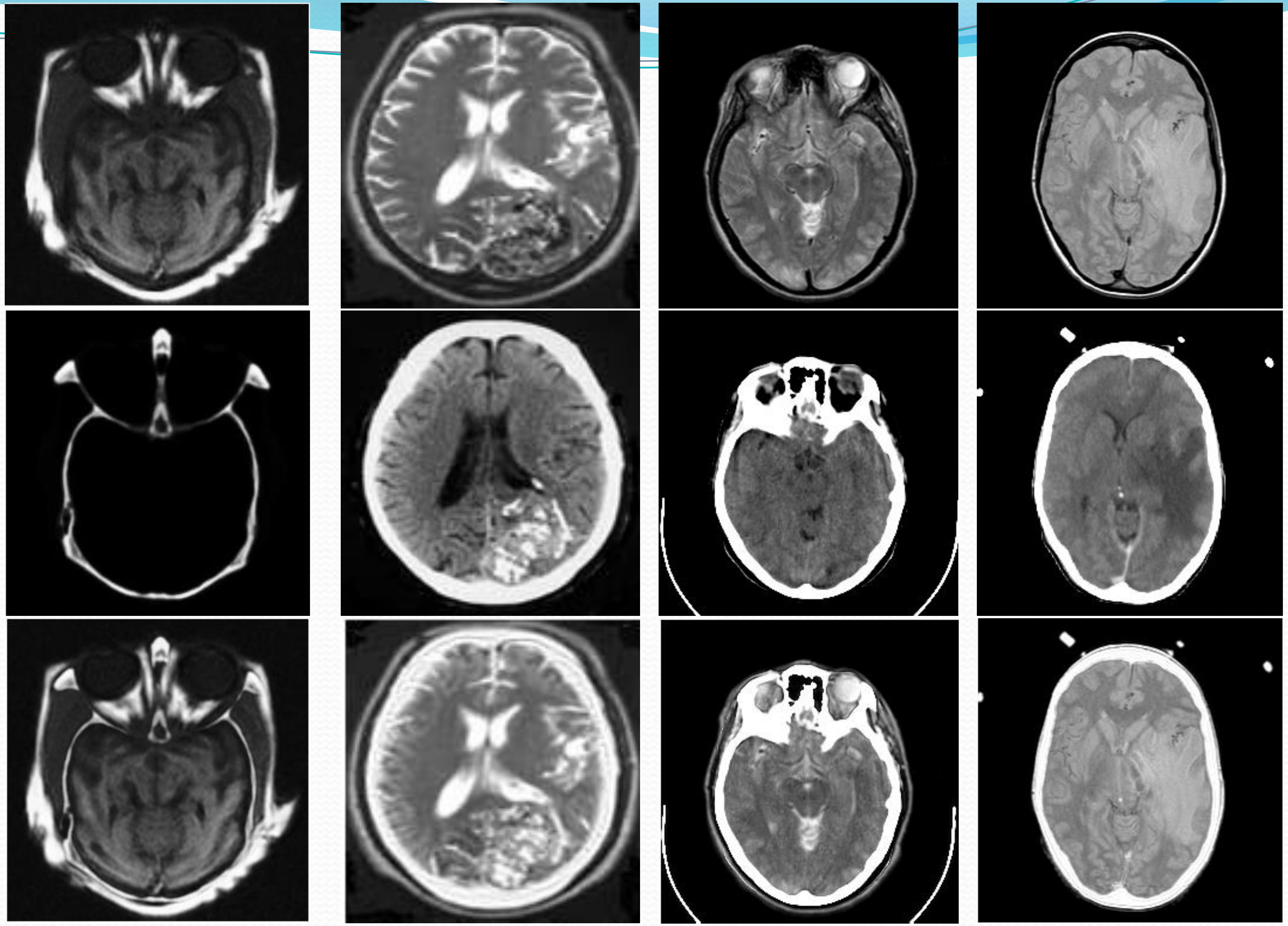
RESULTS

MR and CT Image Fusion Visual Assessment

MR Image

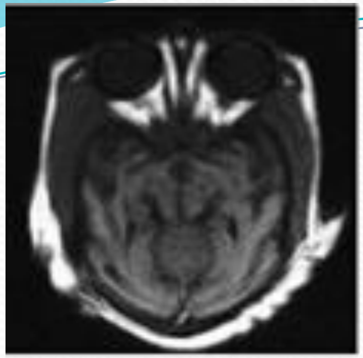
CT Image

Fused Image

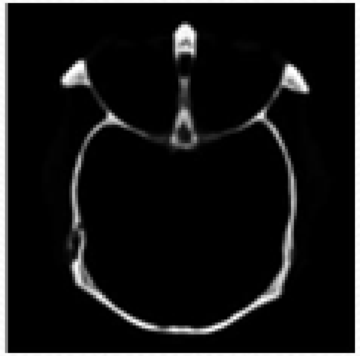


Group (1) Group (2) Group (3) Group (4)

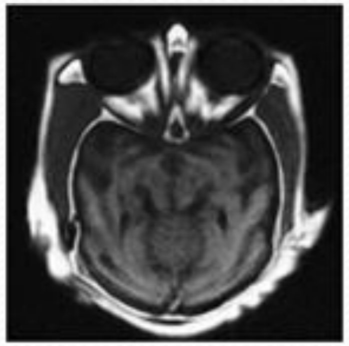
MRI



CT

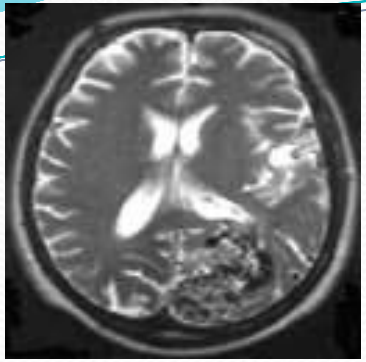


Fused Image

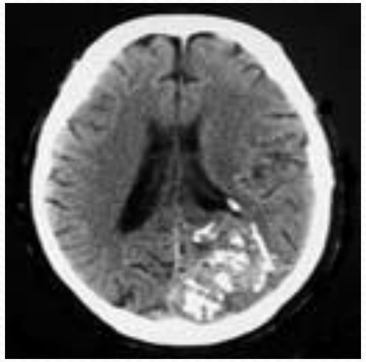


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (1)	256 × 256	CC	0.90900084	0.430389148	
		MI	5.72068838	0.638169642	
		SSIM	0.906993899	0.106697592	
		FSIM	0.979774652	0.889229095	
		ESSIM	0.999996274	0.9999833	
		Entropy	6.632769662	2.03249879	6.767283
		$Q^{AB/F}$			0.79241256
		Edge intensity			0.277694381
		Contrast			0.705344721
		Std			0.000947029
		Variance			0.058319406
		Processing time	748.29		

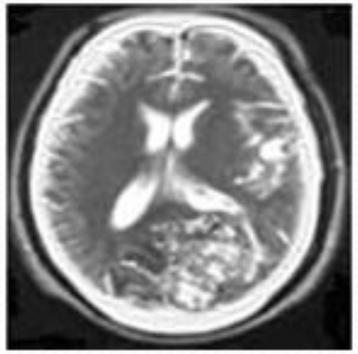
MRI



CT

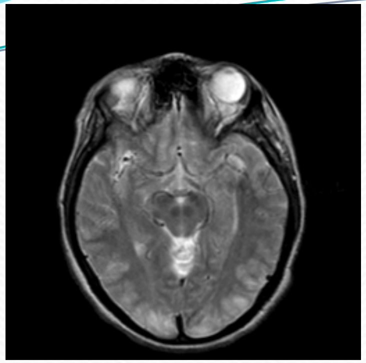


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (2)	256 × 256	CC	0.713766698	0.784107114	
		MI	4.022519498	2.477958461	
		SSIM	0.711480552	0.435867403	
		FSIM	0.938612873	0.955728907	
		ESSIM	0.999988627	0.999985226	
		Entropy	7.5222432	7.275402243	7.724506969
		$Q^{AB/F}$			0.548663312
		Edge intensity			0.570161371
		Contrast			0.653849888
		Std			0.001125836
		Variance			0.082424603
		[illegible]	190.524		

MRI

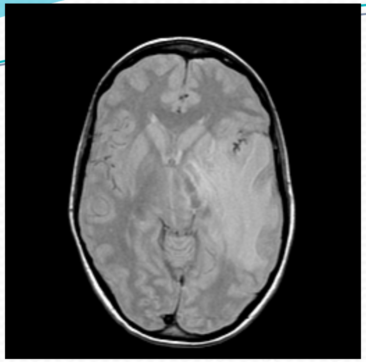


CT

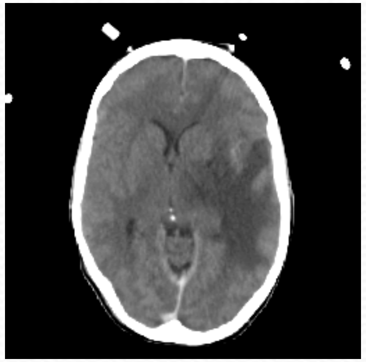
Fused Image

Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (3)	256 × 256	CC	0.689414907	0.935889626	
		MI	1.642479526	1.6346501	
		SSIM	0.722001059	0.800829297	
		FSIM	0.931278646	0.962363132	
		ESSIM	0.999984676	0.999992764	
		Entropy	3.445887215	2.677120664	4.4332992
		$Q^{AB/F}$			0.618814981
		Edge intensity			0.316511364
		Contrast			0.713645118
		Std			0.001329755
		Variance			0.114982119
		[illegible]	[illegible]		

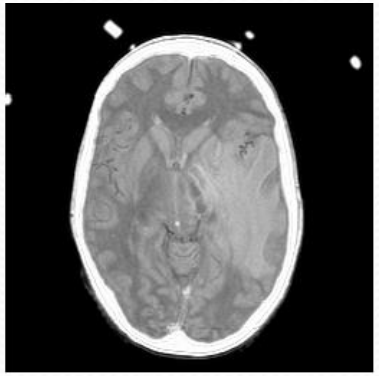
MRI



CT

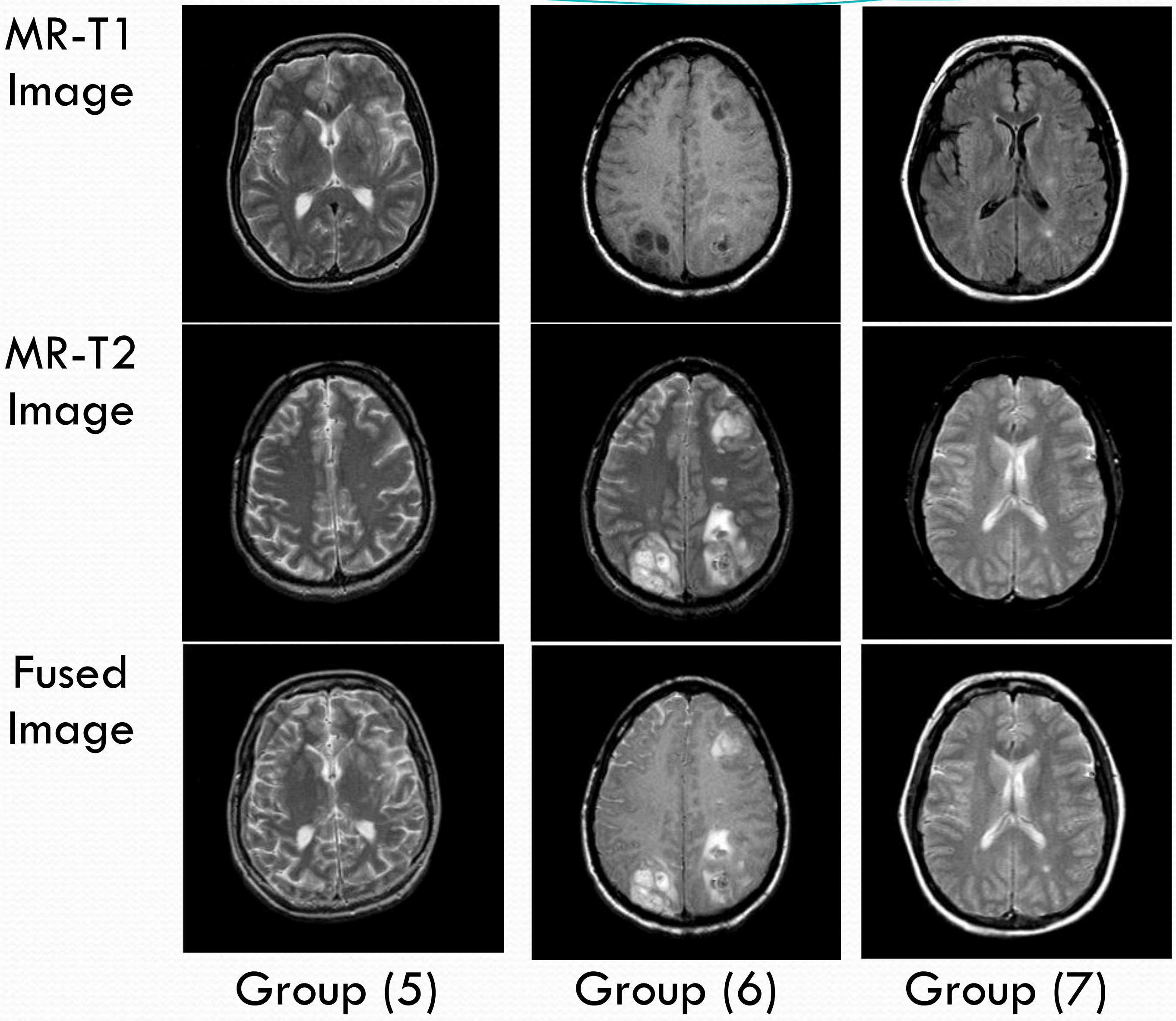


Fused Image

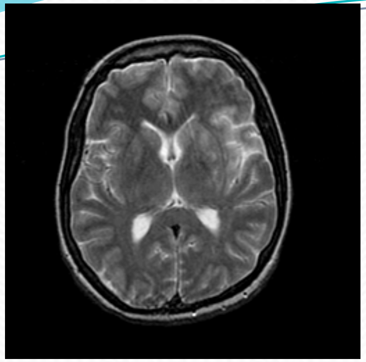


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (4)	256 × 256	CC	0.771747	0.932452	
		MI	5.116124	4.113328	
		SSIM	0.8484	0.754678	
		FSIM	0.956777	0.971081	
		ESSIM	0.999993	0.999994	
		Entropy	3.095738	2.946452	3.914439
		$Q^{AB/F}$			0.510797
		Edge intensity			0.199764
		Contrast			0.500548
		Std			0.001348
		Variance			0.118085
		[illegible]	[illegible]		

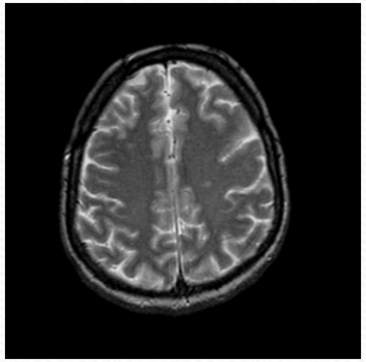
MR-T1 and MR-T2 Image Fusion Visual Assessment



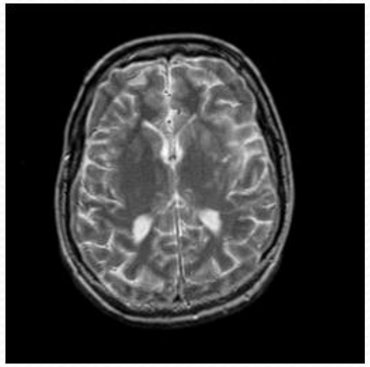
MRI-T1



MRI-T2

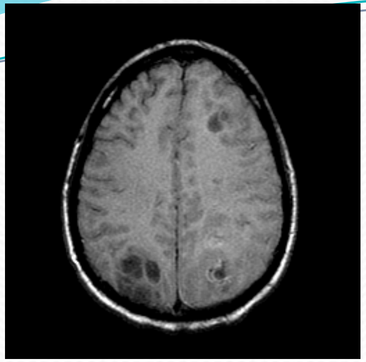


Fused Image

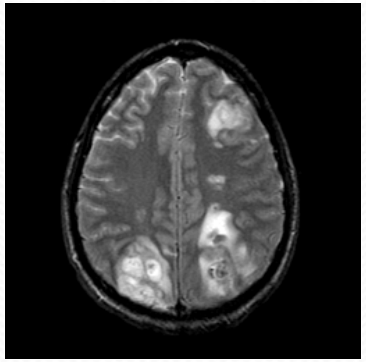


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (5)	256 × 256	CC	0.927954	0.863742	
		MI	1.514447	1.404774	
		SSIM	0.809433	0.771421	
		FSIM	0.968679	0.920927	
		ESSIM	0.999996	0.999992	
		Entropy	3.331931	3.080996	4.443287
		$Q^{AB/F}$			0.568379
		Edge intensity			0.253153
		Contrast			0.683801
		Std			0.000902
		Variance			0.052963

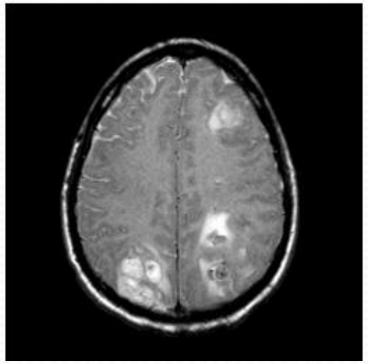
MRI-T1



MRI-T2

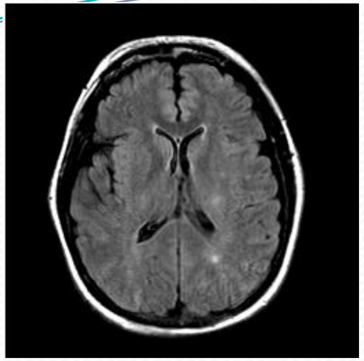


Fused Image

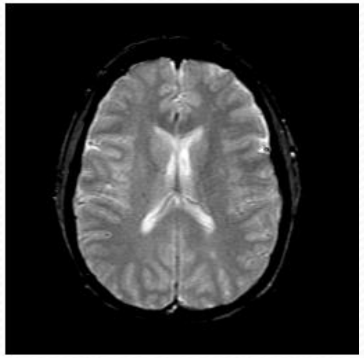


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (6)	256 × 256	CC	0.94363	0.939285	
		MI	1.560381	1.853057	
		SSIM	0.827096	0.795939	
		FSIM	0.976099	0.961695	
		ESSIM	0.999998	0.999997	
		Entropy	2.974882	3.209406	4.080036
		$Q^{AB/F}$			0.575347
		Edge intensity			0.202072
		Contrast			0.5826
		Std			0.001028
		Variance			0.068669
		[illegible]			

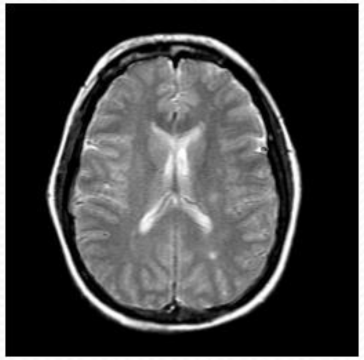
MRI-T1



MRI-T2



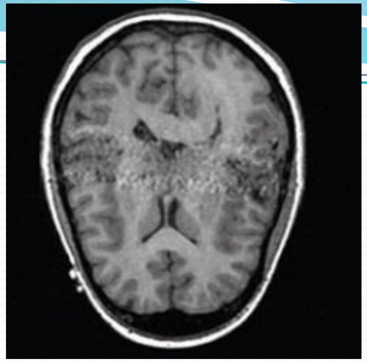
Fused Image



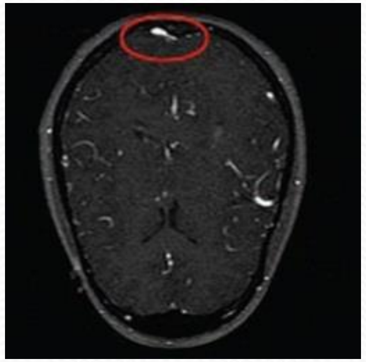
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (7)	256 × 256	CC	0.901617	0.806028	
		MI	3.886894	3.8548755	
		SSIM	0.797326	0.84539	
		FSIM	0.954217	0.890455	
		ESSIM	0.999995	0.999989	
		Entropy	3.585163	3.263062	4.597607
		$Q^{AB/F}$			0.663709
		Edge intensity			0.285927
		contrast			0.666949
		Std			0.001091
		Variance			0.077343

MR and MRA Image Fusion Visual Assessment

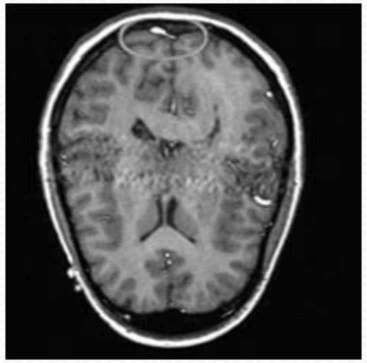
MRI-T1



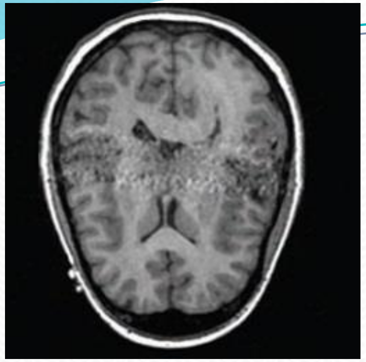
MRA



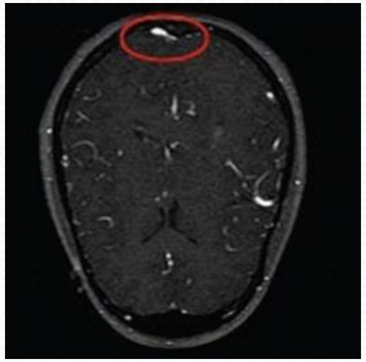
Fused Image



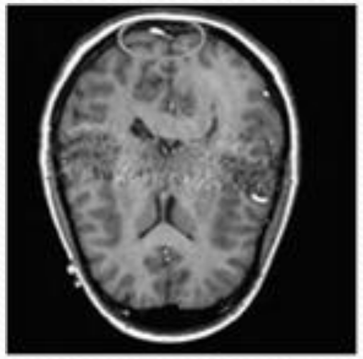
MRI-T1



MRA



Fused Image



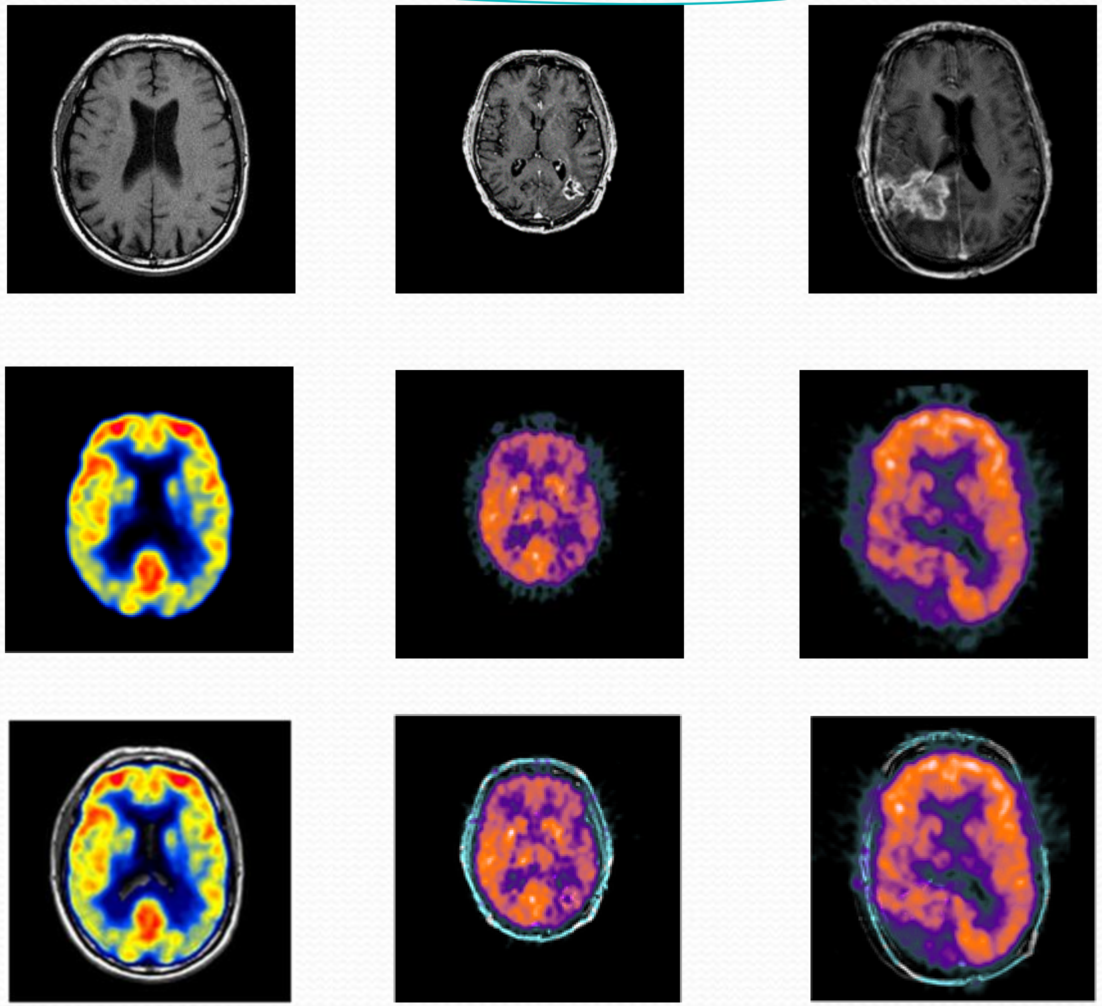
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (8)	256 × 256	CC	0.989288	0.865892	
		MI	3.464962	2.170595	
		SSIM	0.956741	0.588246	
		FSIM	0.994743	0.937595	
		ESSIM	0.999999	0.999992	
		Entropy	5.867818	4.911601	5.888905
		$Q^{AB/F}$			0.646779
		Edge intensity			0.296677
		contrast			0.67447
		Std			0.001026
		Variance			0.0685

MR and PET Image Fusion Visual Assessment

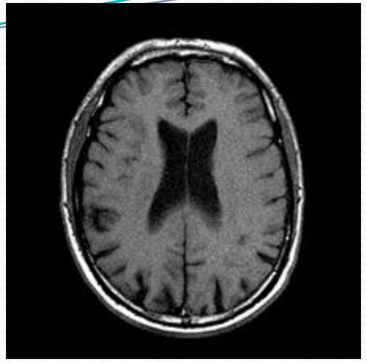
MRI

MRA

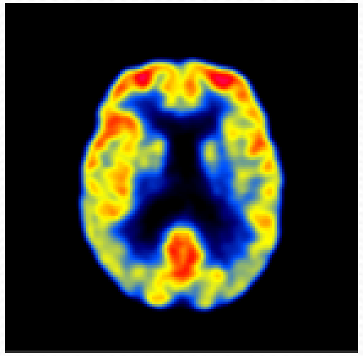
Fused Image



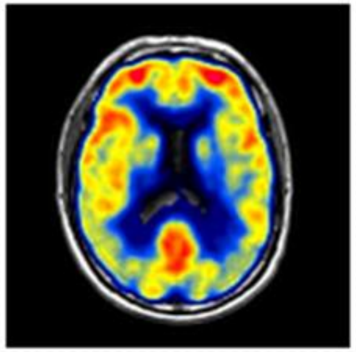
MRI



PET

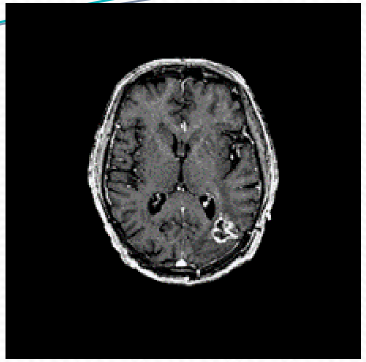


Fused Image

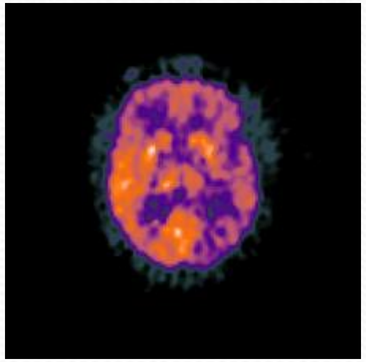


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (9)	128 × 128	CC	0.809284581	0.923783696	
		MI	7.711948915	4.086781781	
		SSIM	0.652608769	0.795028598	
		FSIM	0.92599626	0.953932263	
		ESSIM	0.999989746	0.999983087	
		Entropy	4.424126208	2.689293401	4.59804193
		$Q^{AB/F}$			0.654581741
		Edge intensity			0.429670269
		contrast			0.833683308
		Std			0.001482418
		Variance			0.142905203
		[illegible]	229.2137579		

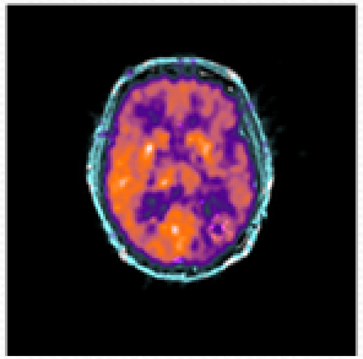
MRI



PET



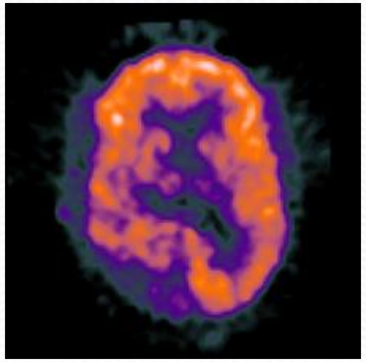
Fused Image



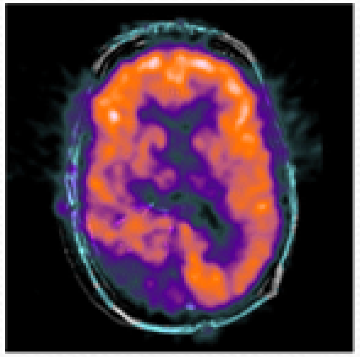
Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (10)	256 × 256	CC	0.831481	0.92047	
		MI	5.540151	6.627818	
		SSIM	0.788781	0.908879	
		FSIM	0.97995	0.985337	
		ESSIM	0.999994	0.999996	
		Entropy	2.272423	2.493845	3.020816
		$Q^{AB/F}$			0.459731
		Edge intensity			0.172135
		contrast			0.61779
		Std			0.00117
		Variance			0.088996
		[illegible]			

MRI

PET

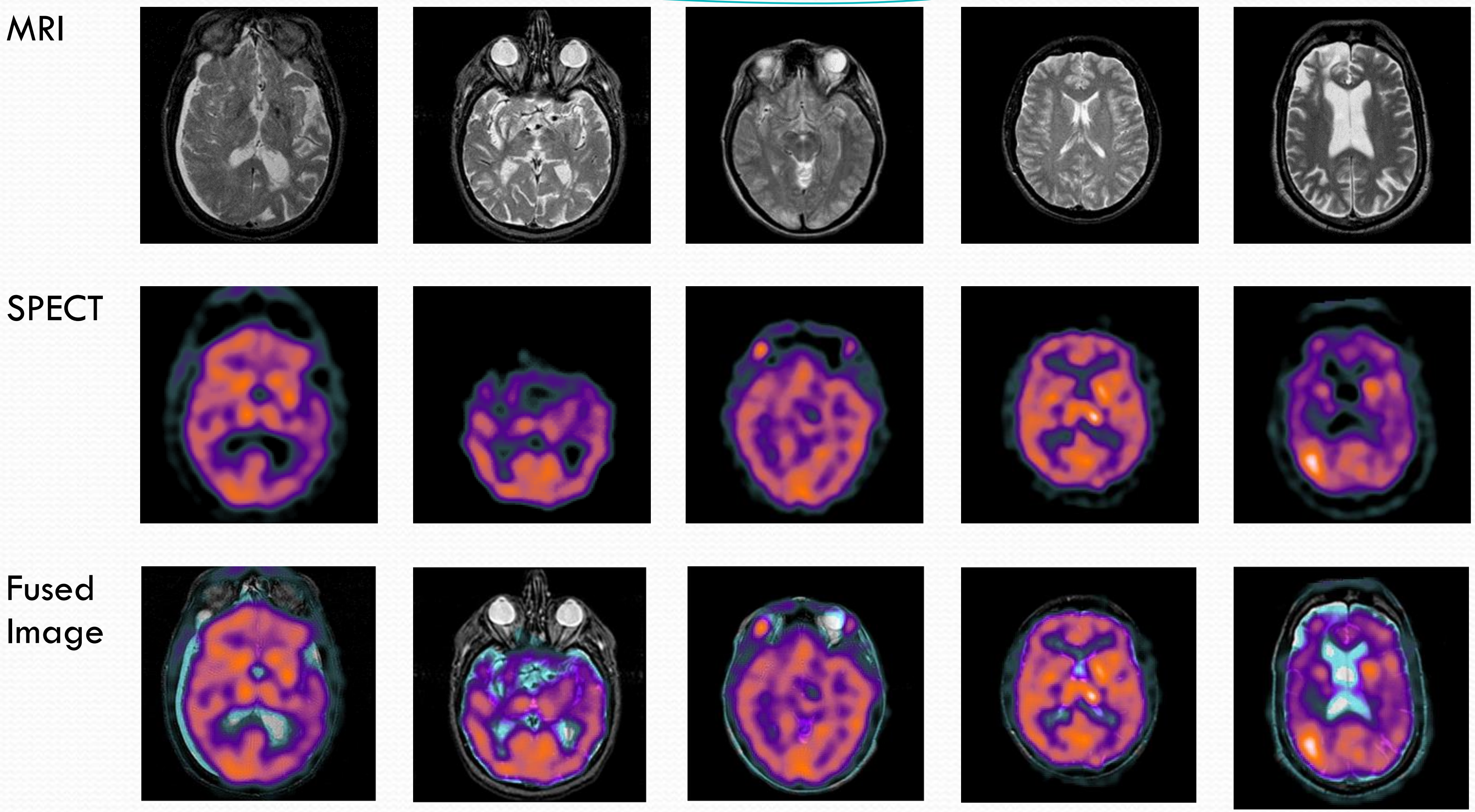


Fused Image

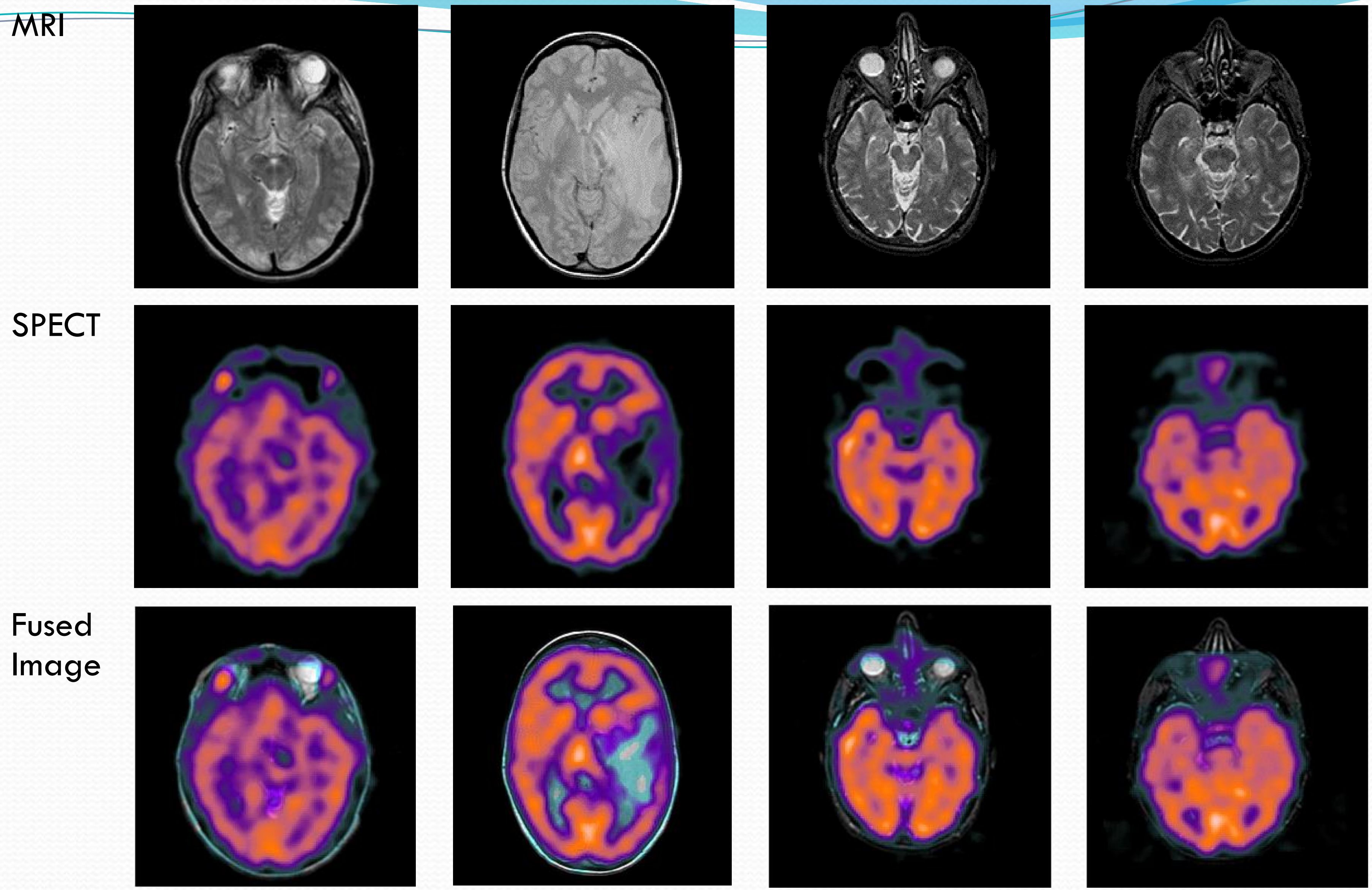


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (11)	256 × 256	CC	0.753566	0.96482	
		MI	3.162081	4.519415	
		SSIM	0.608558	0.841379	
		FSIM	0.92392	0.978479	
		ESSIM	0.999994	0.999995	
		Entropy	3.37178	4.228631	5.596096
		$Q^{AB/F}$			0.537307
		Edge intensity			0.210931
		contrast			0.513534
		Std			0.001308
		Variance			0.111219

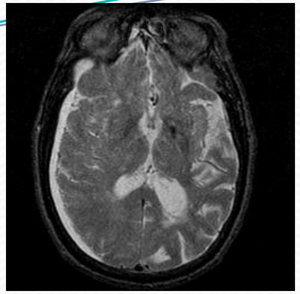
MR and SPECT Image Fusion Visual Assessment



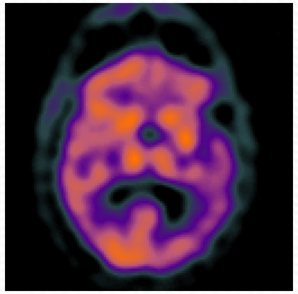
MR and SPECT Image Fusion Visual Assessment



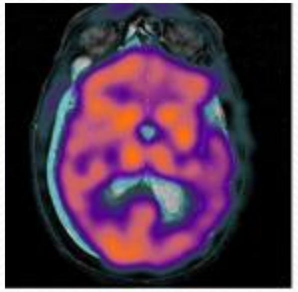
MRI



SPEC
T

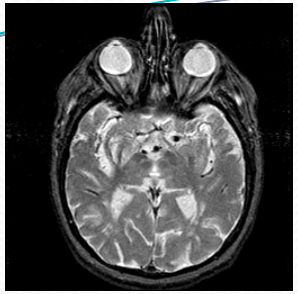


Fused
Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (12)	256 × 256	CC	0.85418	0.917017	
		MI	2.961911	3.703394	
		SSIM	0.704628	0.651403	
		FSIM	0.900458	0.941809	
		ESSIM	0.999995	0.999995	
		Entropy	4.652689	4.404903	6.20432
		$Q^{AB/F}$			0.450012
		Edge intensity			0.206923
		contrast			0.485158
		Std			0.001174
		Variance			0.089673

MRI



SPEC
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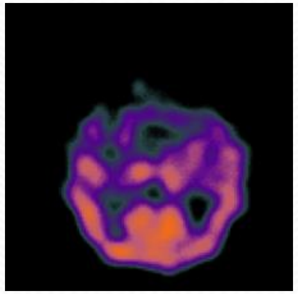
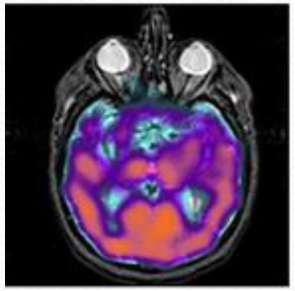
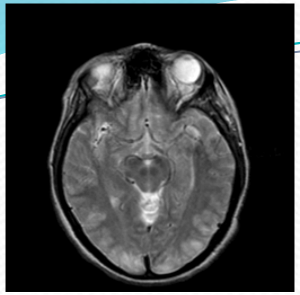


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (13)	256 × 256	CC	0.948151	0.804876	
		MI	1.925117	1.286948	
		SSIM	0.815497	0.567972	
		FSIM	0.958429	0.83989	
		ESSIM	0.999995	0.999985	
		Entropy	4.484795	2.499	5.641238
		$Q^{AB/F}$			0.53921
		Edge intensity			0.279278
		contrast			0.636508
		Std			0.001182
		Variance			0.090817

MRI



SPEC
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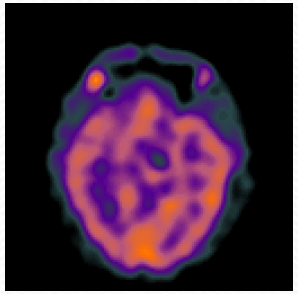
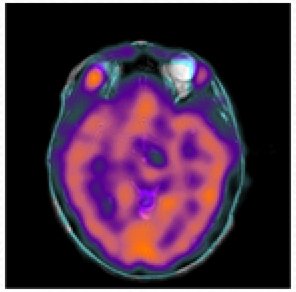
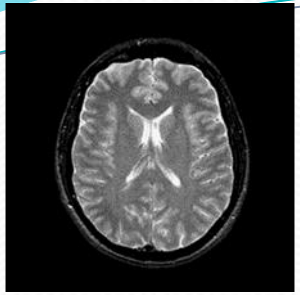


Fused
Image

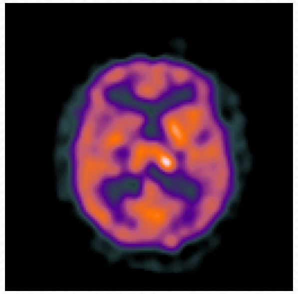


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (14)	256 × 256	CC	0.903712	0.944181	
		MI	4.055668	4.856969	
		SSIM	0.74744	0.834151	
		FSIM	0.933578	0.97544	
		ESSIM	0.999996	0.999997	
		Entropy	3.445887	3.491055	4.745352
		$Q^{AB/F}$			0.472339
		Edge intensity			0.164372
		contrast			0.468891
		Std			0.001194
		Variance			0.092753
		[illegible]			

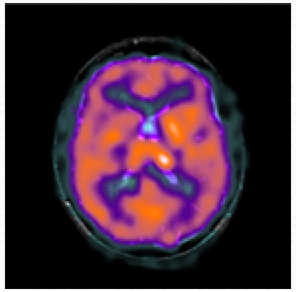
MRI



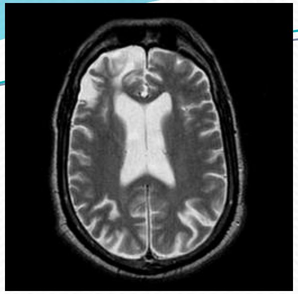
SPEC
T

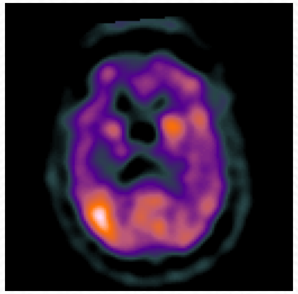


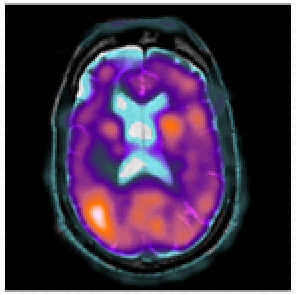
Fused
Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (15)	256 × 256	CC	0.934599	0.981366	
		MI	1.59347	3.078105	
		SSIM	0.72431	0.892027	
		FSIM	0.963792	0.981066	
		ESSIM	0.999994	0.999998	
		Entropy	3.174119	3.483786	4.279645
		$Q^{AB/F}$			0.44373
		Edge intensity			0.144671
		contrast			0.479296
		Std			0.001243
		Variance			0.100484

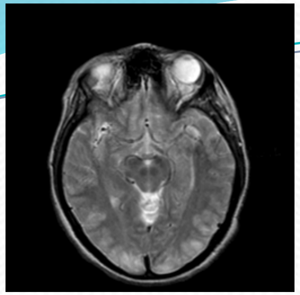




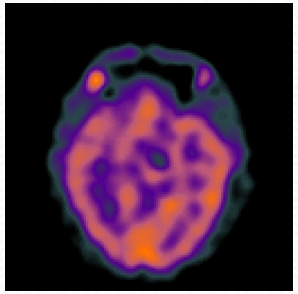


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (16)	256 × 256	CC	0.909489	0.843865	
		MI	1.423243	2.617246	
		SSIM	0.756473	0.739328	
		FSIM	0.956783	0.953602	
		ESSIM	0.999995	0.999994	
		Entropy	3.895176	3.681655	5.016085
		$Q^{AB/F}$			0.50045
		Edge intensity			0.195166
		contrast			0.521311
		Std			0.001188
		Variance			0.091726
		[illegible]			

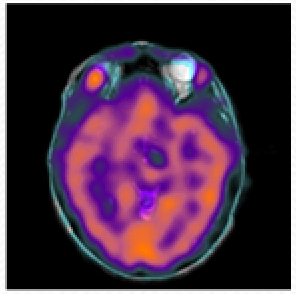
MRI



SPECT

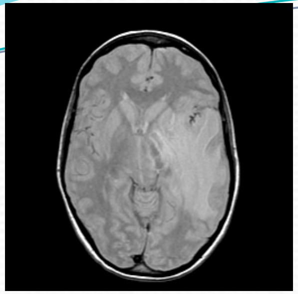


Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (17)	256 × 256	CC	0.899382	0.94696	
		MI	1.79986	3.314436	
		SSIM	0.709034	0.881427	
		FSIM	0.929109	0.978645	
		ESSIM	0.999995	0.999997	
		Entropy	3.445887	3.491055	4.370006
		$Q^{AB/F}$			0.487484
		Edge intensity			0.152893
		contrast			0.456982
		Std			0.001193
		Variance			0.092559
		[illegible]			

MRI



SPEC
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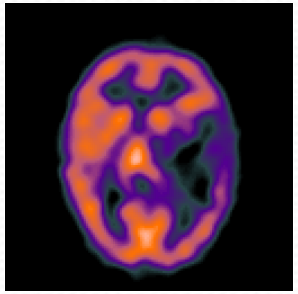
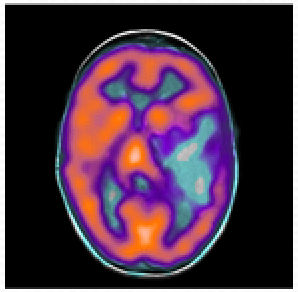
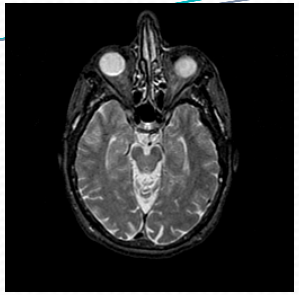


Fused
Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (18)	256 × 256	CC	0.944995	0.909792	
		MI	4.654303	4.986795	
		SSIM	0.833974	0.771147	
		FSIM	0.945638	0.949615	
		ESSIM	0.999997	0.999993	
		Entropy	3.095738	3.401559	4.472392
		$Q^{AB/F}$			0.546984
		Edge intensity			0.196263
		contrast			0.467758
		Std			0.001338
		Variance			0.116362
		Processing			

MRI



SPEC
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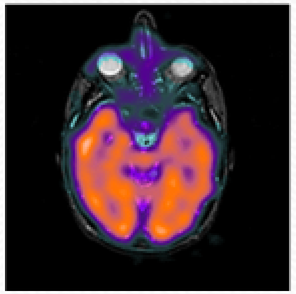
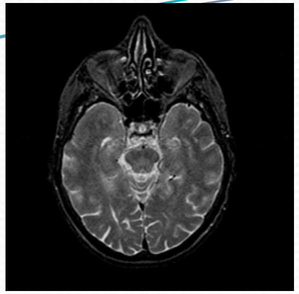
Fused
Image

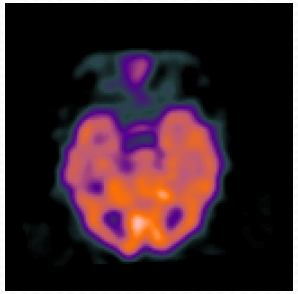


Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (19)	256 × 256	CC	0.86591	0.958054	
		MI	1.636563	2.52507	
		SSIM	0.762349	0.850464	
		FSIM	0.963519	0.976275	
		ESSIM	0.999994	0.999996	
		Entropy	2.988912	2.80937	3.977578
		$Q^{AB/F}$			0.416947
		Edge intensity			0.144331
		contrast			0.548611
		Std			0.001222
		Variance			0.097155

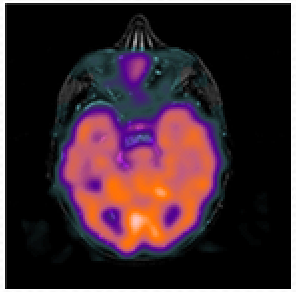
MRI



SPECT



Fused Image



Datasets	Size	Metric	Fused, image1	Fused, image2	Fused image
Group (20)	256 × 256	CC	0.852913	0.990854	
		MI	1.330145	3.144966	
		SSIM	0.685346	0.893473	
		FSIM	0.947997	0.979815	
		ESSIM	0.999993	0.999998	
		Entropy	3.068157	3.333017	4.237963
		$Q^{AB/F}$			0.394274
		Edge intensity			0.118867
		contrast			0.453822
		Std			0.001226
		Variance			0.097755

COMPARISON WITH EXISTING M

Methods	**Metrics**			
	Entropy	MI	SSIM	$Q^{AB/F}$
CNN (2017)	6.1741	-	-	--
CNN (2018)	6.5997	2.6023	0.5676	0.7276
CNN and shearlet transform (2018)	**6.7612**	**5.7545**	-	-
Curvelet transform and GA (2020)	-	3.3121	-	0.4262
Non-subsampled shearlet transform (2018)	6.4179	2.3761	-	-
Sparse Representation (2017)		4.6721		0.6677
Fuzzy Logic in NSCT (2016)	-	4.5619		0.7859
Biorthogonal wavelet transform (2019)	5.9985	1.7880	-	0.6672
2nd Proposed method	**6.767283**	**5.720688**	**0.903683**	**0.792**

COMPARISON BETWEEN THE TWO PROPOSED METHODS

Datasets	Size	Metric	1st Proposed Method	2nd Proposed Method
Group (1)	256 × 256	CC	0.906401	0.90900084
		MI	3.8827	5.72068838
		SSIM	0.8922	0.906993899
		FSIM	0.979543	0.979774652
		ESSIM	0.999996	0.999996274
		Entropy	6.7574	6.767283
		$Q^{AB/F}$	0.7586	0.79241256
		Edge intensity	0.281595	0.277694381
		contrast	0.728277	0.705344721
		Std	0.000947	0.000947029
		Variance	0.058325	0.058319406
		[illegible]	[illegible]	[illegible]

Outlines

- Introduction
- Problem definition
- Thesis objectives
- Literature review and related work
- Proposed methods
- Experimental results
- Conclusion
- Future work

Conclusion

- Multimodality medical image fusion seeks to merge information from diverse images to attain a more informative image.
- Most of the researchers are directed toward transform domain pixel-level schemes.
- The prominent pixel-based fusion approaches include different transform strategies, dictionary learning, guided filtering, and intelligent methods.
- Merging more than one image fusion pixel-level approaches is effective in medical image analysis.
- The hybrid systems of both pixel-level and feature-level image fusion combines the advantages of both methods and avoids their drawbacks.
- The deep learning methods in the area of image fusion have become an active topic due to its high ability in feature extraction and data representation.

Outlines

- Introduction
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Future Work

- Enhancement the hybrid pixel and feature-level fusion methods for multimodality medical image fusion.
- Decision-level medical image fusion approach needs further extensive research and exploration.
- Improvement of image fusion technique based on different optimization technique
- The application of deep learning techniques in the field of medical image fusion has also emerged as an active topic in the last years.

Publications

1. Nahed Tawfik, Heba A. Elnemr, Mahmoud Fakhr, Moawad I. Dessouky, and Fathi E. Abd El-Samie, "Survey Study of Multimodality Medical Image Fusion Methods", *Multimedia Tools and Applications*, 2020, https://doi.org/10.1007/s11042-020-08834-5, Impact factor: 2.313 (Q2)
2. Nahed Tawfik, Heba A. Elnemr, Mahmoud Fakhr, Moawad I. Dessouky, and Fathi E. Abd El-Samie, "Hybrid Pixel-Feature Fusion System for Multimodal Medical Images", Journal of Ambient Intelligence and Humanized Computing, 2020, https://doi.org/10.1007/s12652-020-02154-0, Impact factor: 4.594 (Q1)
3. Nahed Tawfik, Heba A. Elnemr, Mahmoud Fakhr, Moawad I. Dessouky, and Fathi E. Abd El-Samie, "Multimodal medical image fusion based on sacked autoencoder and NSCT domain", under review.

Thank you!