# A PROJECT REPORT ON

**IMAGE FUSION USING DISCRETE WAVELET TRANSFORM**

**IN MATLAB**

**Submitted in partial fulfillment of the requirements Of the degree of**

# Bachelor of Technology

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**ELECTRONICS AND COMMUNICATION ENGINEERING**

**RAJIV GANDHI UNIVERSITY OF KNOWLEDGE AND TECHNOLOGIES**

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# Candidate’s Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included. I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will cause disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission had not been taken when needed.

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## Certificate

This is to certify that the report entitled ‘IMAGE FUSION USING DISCRETE WAVELET TRANSFORM IN MATLAB’ submitted by Yarramsetti Hemasri-(o190823), Kanneboina ArunKumar-(o190421), Surapaneni Pujitha-(o190288), Nakka V Anitha-(o190267) and Lakkipogu Pattu-(o190379) in partial fulfilment of the requirements for the award of Bachelor of Technology in Electronics and communication Engineering is a bonafide work carried by them under my supervision and guidance.

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### Abstract

Image fusion is a critical process in various applications such as remote sensing, medical imaging, and military surveillance, where it aims to combine relevant information from multiple images into a single image that is more informative and useful than the individual sources. This paper presents a method for image fusion using the Discrete Wavelet Transform (DWT) implemented in MATLAB.

The MATLAB implementation includes the following steps: (1) Decomposing the input images into approximation and detail coefficients using DWT; (2) Applying fusion rules to combine these coefficients; (3) Reconstructing the fused image by performing the inverse DWT on the combined coefficients. Various fusion rules such as maximum selection, weighted averaging, and region-based fusion are explored to determine the optimal approach for different application scenarios.

Experimental results demonstrate that the DWT-based fusion method enhances image quality, improving visual clarity and detail compared to traditional methods. Quantitative analysis using metrics like entropy, mutual information, and edge preservation further validates the effectiveness of the proposed approach. The fusion technique's robustness and versatility highlight its potential for real-world applications where enhanced image quality is paramount

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**INTRODUCTION**

### Introduction

Image processing is the analysis of digital images using various methods and techniques[1]. The steps involved in image processing are image acquisition, image enhancement, etc. These steps make image processing much easier. Image processing encompasses many techniques for the visualization of images. Image fusion is one of the important techniques used for enhancing the image [2]. Researchers merged some number of images of satellites to get a more informative representation of the Earth in the twentieth century. In earlier days, the operations used in image fusion were addition, multiplication, subtraction, and so on.

Now the technology has evolved and some of the methods used for image fusion are Deep neural networks (DNN), Wavelet Transforms, Multiresolution Analysis, etc.

Image Fusion integrates two or more images which results in an image called a fused image. Image fusion techniques are classified as pixel-level and feature-level fusion. Pixel-level fusion combines and arranges pixels to form an output image. In feature-level fusion, features such as colors, edges, and textures of an input image are taken into consideration to form an output image[3]. Pixel-level fusion methods have the concept of averaging pixels of an input image. It also includes median, maximum, and minimum operations. Feature-level fusion methods involve the decomposition of input images, also known as multi-resolution analysis. Discrete Wavelet Transform (DWT) is a technique used to decompose images into their frequency components[4]. The sub-band that contains the most energy is selected for fusion so that the resultant image obtained can be more informative. Sometimes DWT and PCN techniques are used together to create more effective fusion methods [5].

Image fusion is widely used in many fields like medical sectors, remote sensing, etc. Computed Tomography(CT), Magnetic Resonance Imaging (MRI) techniques, etc come under the medical sector [6]

**1.2 Related work**

**MRI Scan**

Paul Lauterbur and Sir Peter Mansfield 1973 invented the magnetic Resonance Imaging (MRI) technique. MRI techniques form accurate images of internal structures using magnetic fields. Image fusion techniques combine MRI images with CT scans, to obtain more detailed information. In brain imaging, MRI can help to detect abnormalities of the structure. Sometimes MRI alone cannot provide helpful information about the image to make a clear diagnosis. Techniques used in MRI-based-image fusion are intensity-based fusion, featurebased fusion, and hybrid fusion. Intensity-based fusion involves fusing images based on their intensity values. Feature-based fusion consists in extracting features of images. As discussed earlier, feature-based fusion uses wavelet transform. In MRI-based image fusion, DWT can be used to extract features from the MRI data to combine with other image modality like CT scan [7].

**CT Scan**

In 1967, the idea of creating computer-assisted tomography came to a British Electrical Engineer, Sir Godfrey Hounsfield, at EMI central research laboratories, using X-ray technology. It was first commercially available in 1971 to perform a brain CT scan in Wimbledon, England. Later, the MRI scan was invented. Computerized tomography (CT) scan unify a collective set of images of x-ray scans onto a single sheet. It uses computer processing to scan[8]. CT scans provide more detailed information about diagnosing bone and muscle disorders and fractures. People get CT scans of their pain to detect any injuries, so they can get treatment.

### 2.OBJECTIVES

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### To understand the fundamental principles of Discrete Wavelet Transform.

### To implement image fusion using DWT in MATLAB.

### To evaluate the performance of the fused images in terms of quality and information content.

### To explore different fusion rules and their impact on the fused image quality.

### To discuss the advantages, challenges, and potential improvements in image fusion using DWT.

### 

### 3.BACKGROUND

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### 3.1 Image fusion

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### 

Image fusion using the Discrete Wavelet Transform (DWT) in MATLAB is a sophisticated method designed to merge multiple images into a single composite image that preserves the most important features from each input image. This technique is widely used in fields such as medical imaging, remote sensing, surveillance, and computer vision to enhance image quality and provide more comprehensive information.

The fusion process begins by reading and preprocessing the input images to ensure they are of the same size, as alignment is crucial for effective fusion. If the images are in color, they are often converted to grayscale to simplify the process. The Discrete Wavelet Transform (DWT) is then applied to each image, breaking them down into various sub-bands representing different frequency components. This decomposition results in approximation coefficients that capture low-frequency information (coarse details) and detail coefficients that capture high-frequency information (fine details) in horizontal, vertical, and diagonal directions.

Once the images are decomposed into their respective wavelet sub-bands, the next step is to fuse the corresponding coefficients from each input image. The choice of fusion rule is critical and can vary depending on the application. Common fusion rules include selecting the maximum absolute value, averaging the coefficients, or using weighted combinations to emphasize certain features. More advanced decision-based rules can also be employed, such as selecting coefficients based on local variance or gradient information to better preserve significant features.

After fusing the coefficients, the inverse Discrete Wavelet Transform (IDWT) is applied to reconstruct the final fused image. This step combines the fused approximation and detail coefficients to form a single image that integrates the critical information from all input images. The result is a composite image that offers enhanced visual quality and retains essential features from each original image.

Post-processing techniques can be applied to the fused image to further enhance its quality or adapt it to specific needs. These techniques might include contrast adjustment, noise reduction, or edge enhancement. The final image can then be displayed using MATLAB's visualization tools to assess the effectiveness of the fusion process.

The advantages of using DWT for image fusion are numerous. DWT allows for multi-resolution analysis, capturing both broad and fine details. It efficiently integrates information from multiple sources, providing a comprehensive view of the scene. The flexibility in fusion rules allows customization for various applications, and the process can also help reduce noise by combining data from different images. These features make DWT-based image fusion a powerful tool in enhancing image quality and extracting valuable information from multiple sources.

**3.2 Discrete wavelet transform**

DWT is any wavelet transform for which the wavelets are discretely sampled. It captures both frequency and location information.

DWT is a technique that is used for signal processing that decomposes the signal or image into a collection of wavelets[13]. These wavelets have different signal frequency components. The mother wavelet function gets translated and then a generation of wavelets 3 E3S Web of Conferences 391, 01076 (2023) https://doi.org/10.1051/e3sconf/202339101076 ICMED-ICMPC 2023 takes place. By using DWT we can sample discretely the input function or wavelet. It is preferable to other wavelet transform techniques because it can capture both frequency and location.



**4.Methodology**

Many fusion techniques can be performed on images. They are classified as Spatial and Frequency domains. The spatial domain involves pixel values of images. By using Fourier Transform the image pixel values can be evaluated Fourier Transform methods include High pass filtering, PCA, Brovery method, and others. The frequency domain overcomes the drawback of spatial distortions that are caused by Spatial domain techniques. The techniques involved in the frequency domain are the Laplacian pyramid fusion technique, Discrete Cosine Transform, etc. Discrete Wavelet Transform provides information about both spatial and frequency domains.

**4.1 Image preprocessing**

Image preprocessing plays a pivotal role in the success of image fusion, which involves merging multiple images into a single composite that encapsulates the most valuable information from each source. The first step often involves noise reduction, which aims to remove unwanted noise that can obscure important details. Techniques such as median filtering, Gaussian smoothing, and wavelet transforms are commonly utilized to enhance image clarity and detail.

Following noise reduction, image registration is performed to align images from different sources to a common coordinate system. This alignment is crucial because it ensures that corresponding features in different images coincide precisely, which is necessary for effective fusion. Methods such as feature matching, mutual information maximization, and the use of control points help achieve accurate alignment.

Intensity normalization is another essential preprocessing step, where the brightness and contrast of the images are adjusted to a consistent scale. This step is critical in minimizing the differences in illumination and enhancing the visibility of features, which can vary due to differing sensor characteristics or environmental conditions during image capture.

Geometric correction is also performed to address any distortions in the images that may result from sensor inaccuracies, platform movement, or terrain relief. Techniques such as polynomial transformations or spline interpolation are employed to correct these distortions, ensuring the spatial accuracy of the images.

Histogram matching is often used to adjust the histograms of the images so that their intensity distributions are similar. This step is particularly important when dealing with images from different sensors, as it helps standardize their appearance, making it easier to fuse them seamlessly.

By meticulously applying these preprocessing techniques, the quality and consistency of the input images are significantly enhanced. This not only improves the robustness of the subsequent fusion process but also ensures that the final fused image is of high quality, with enhanced clarity, accuracy, and informational value. Preprocessing thus sets the foundation for successful image fusion, enabling the extraction of meaningful and reliable information from the combined images.

**4.1.1 Image selection**

In your project, focusing on image selection and image registration are crucial steps within the broader field of image processing, especially when dealing with tasks like object recognition or image fusion. Here's how each of these components plays a role in your project:

**Image Selection:**

Image selection involves choosing the most appropriate images from available datasets or sources based on specific criteria relevant to your project. Here’s a detailed approach:

**1. Define Selection Criteria:** Purpose: Determine the specific objectives of your project (e.g., object detection, image fusion). Quality: Ensure images meet quality standards (e.g., resolution, clarity, absence of artifacts). Content Relevance: Select images that contain the features or objects of interest related to your project. Diversity: Include images with different viewpoints, lighting conditions, and variations to ensure robustness in analysis or processing.

**2. Sources of Images:** Public Databases: Utilize established image databases such as ImageNet, COCO, or domainspecific repositories relevant to your project's focus. Custom Data Collection: Acquire images through cameras, sensors, or other sources that capture data specific to your project needs. Data Augmentation: Enhance dataset diversity by generating synthetic images or applying transformations (e.g., rotation, scaling) to existing images.

**3. Preprocessing:** Normalization: Ensure all selected images are in a standardized format, resolution, and color space suitable for subsequent processing steps. Quality Assessment: Perform checks to eliminate images with issues such as blur, noise, or other artifacts that could impact analysis accuracy.

**4. Tools and Techniques:** Image Processing Libraries: Use tools like MATLAB, Python (OpenCV, scikit-image), or specialized software for tasks such as image enhancement, noise reduction, and quality control.

**Machine Learning Techniques:** Employ algorithms for automated image selection based on predefined criteria, potentially integrating clustering, similarity metrics, or deep learning approaches for relevance ranking.

**4.1.2 Image registration**

**Image Registration:**

Image registration involves aligning two or more images to a common coordinate system, which is essential for accurate comparison or fusion. Here’s how it fits into your project:

1. **Types of Registration:**

**Spatial Alignment:** Adjust images to correct for translation, rotation, scaling, or perspective differences.

**Feature-Based Registration:** Match key features or landmarks across images for precise alignment. **Intensity-Based Registration:** Optimize alignment by minimizing differences in pixel intensity distributions between images.

**2.Methods and Algorithms:**

**Manual Registration:** Perform visual alignment based on identifiable features or landmarks in images.

**Automated Registration:** Implement algorithms like iterative closest point (ICP), affine transformations, or mutual information maximization for accurate and efficient registration.

**3.Applications in Your Project:**

**Image Fusion:** Combine registered images to enhance visual quality or extract more comprehensive information.

**Multispectral Imaging:** Integrate data from different imaging modalities (e.g., visible and infrared) for comprehensive analysis.

**Medical Imaging:** Align images from different scans (e.g., MRI, CT) for precise diagnosis or treatment planning.

**4. Implementation:**

**Software Tools:** Utilize specialized software packages or programming libraries that offer registration functionalities, ensuring compatibility with your chosen image processing environment (e.g., MATLAB’s Image Processing Toolbox, Insight Segmentation and Registration Toolkit - ITK).

Project Integration

Integrate image selection and registration seamlessly into your project workflow to ensure that the chosen images are appropriately prepared and aligned for subsequent processing tasks such as image fusion, segmentation, or feature extraction. Consider the specific requirements of your project and adjust methodologies accordingly to achieve optimal results in image processing and analysis.

By focusing on these steps, you can effectively manage image data quality, relevance, and alignment, thereby enhancing the accuracy and reliability of your project outcomes in image processing.

**4.2 Discrete wavelet transform**

DWT technique is a tool used for image fusion widely used in remote sensing, medical imaging, and computer vision. This technique provides a multi-resolution decomposition of the input image. It also provides energy compaction, edge detection, multi-resolution analysis, etc.

DWT can be used for image fusion by decomposing the input images into wavelet coefficients. The coefficients are then fused to reconstruct the fused image.

For image fusion, the DWT technique is used commonly because it can capture both frequency and location of the input image.

**4.2.1 Decomposition**

In image fusion using the DWT technique, decomposition is a fundamental step. The image is broken into multi-level wavelet coefficients in this process. High-pass and low-pass filters are applied to input images to extract the different frequency components at different levels using the DWT technique. It produces the approximation coefficient in the first level of the decomposition that represents low-frequency information. It also gives a detailed coefficient that represents the high-frequency information. The size of input images will decide the number of decomposition levels. The wavelet coefficients are included in the fusion rule after this decomposition process. These fused coefficients are utilized to construct the fused image.

**4.2.2 Fusion rules**

In image processing, fusion rules are critical in applications such as remote sensing, medical imaging, and surveillance, where combining data from multiple sensors or viewpoints can significantly improve the quality and utility of the resulting images. These rules are designed to leverage complementary information from different sources, enhancing the overall scene understanding and enabling more accurate and robust analysis.

Pixel-level fusion typically involves methods like averaging, principal component analysis (PCA), or wavelet transforms. For instance, averaging might be used to reduce noise by smoothing out discrepancies between images, while PCA can help highlight the most significant features by transforming the data into a space where the main variations are captured by fewer components.

Feature-level fusion goes a step further by focusing on significant attributes like edges, textures, or shapes. Techniques such as edge detection algorithms (e.g., Sobel or Canny) or texture analysis (e.g., Gabor filters) are employed to extract these features from each image. The extracted features are then combined, often using statistical methods or machine learning algorithms, to form a detailed composite image that retains the most critical information from all sources.

Decision-level fusion operates at a higher abstraction level, where each input image or dataset is processed independently to generate decisions or classifications. These individual decisions are then fused using methods such as majority voting, Bayesian inference, or Dempster-Shafer theory to arrive at a final, more reliable decision. This approach is particularly useful in scenarios where different algorithms or sensors may produce varying results, and combining their outputs can enhance overall accuracy and confidence.

Advanced fusion techniques also include multi-resolution analysis, where images are combined at various scales, and deep learning-based fusion, which leverages neural networks to learn optimal fusion strategies from large datasets. These sophisticated methods can capture complex relationships and interactions between input images, leading to superior fusion outcomes.

Ultimately, the selection of appropriate fusion rules is driven by the specific requirements of the application, the nature of the input data, and the desired output. By effectively integrating information from multiple sources, fusion rules play a crucial role in enhancing image quality, improving interpretation, and enabling better decision-making in various image processing tasks.

**4.2.3 Reconstruction**

It is the final step in DWT-based image fusion. Using fused wavelet coefficients the reconstruction will be done. After the fusing of wavelet coefficients, those are used to reconstruct the final fused image by performing the (IDWT)inverse DWT.

The inverse DWT takes the fused wavelet coefficients and combines them to obtain a highresolution image. This is done by applying the inverse DWT in reverse order to the decomposition process used in the image fusion technique. The final reconstructed image is obtained by adding the detail and approximation coefficients from all decomposition levels.

**5. Image fusion techniques**

**Image restoration:**

Image restoration is a crucial task in image processing aimed at improving the quality of degraded images. It involves various techniques to recover details, correct distortions, and enhance overall visual clarity. One of the fundamental approaches is image fusion, where information from multiple images of the same scene is combined to create a composite image that surpasses the quality of any individual input. Techniques like multi-resolution fusion using wavelet transforms decompose images into different frequency bands, allowing for selective combination of high-frequency details and low-frequency structures. Pixel-level fusion methods, such as averaging or weighted averaging, merge corresponding pixels from different images to achieve a balanced, high-quality result. These approaches are essential in fields ranging from medical imaging to remote sensing, ensuring clearer and more informative images for analysis and decision-making.

Image restoration encompasses a variety of techniques designed to recover or enhance the quality of images that have been degraded by factors such as noise, blur, or low resolution. These techniques are essential in fields like medical imaging, surveillance, and satellite imagery analysis where image fidelity directly impacts decision-making and analysis accuracy. Common methods include filtering to reduce noise or blur, deconvolution to reverse blurring effects, and interpolation to enhance resolution. Advanced algorithms such as deep learning-based approaches have also emerged, leveraging neural networks to learn complex mappings

**Image mixing:**

Image mixing, also known as image blending or compositing, is a fundamental technique in digital imaging where two or more images are combined to create a unified composite. This process is pivotal in fields such as digital photography, computer graphics, and multimedia production. One of the most common methods is alpha blending, where transparency values (alpha channels) determine the weight of each image's contribution to the final result, enabling smooth transitions and overlays. Layer blending, used extensively in graphic design software, involves applying blending modes like overlay or multiply to combine layers and achieve desired visual effects. Panorama stitching utilizes image mixing to seamlessly merge multiple photos of a scene, aligning them and blending overlapping areas to create expansive panoramic views. Additionally, HDR imaging employs image blending to fuse multiple exposures of the same scene, capturing a broader dynamic range of light to produce vivid, detailed images. Whether for creating artistic compositions, enhancing visual fidelity, or generating special effects, image mixing techniques play a pivotal role in achieving compelling and impactful digital imagery across diverse applications.

**Image morphing:**

Image morphing is a sophisticated technique in computer graphics and animation that enables the gradual transformation of one image into another. This process involves defining corresponding points or features between the two images, establishing a mesh or triangulation based on these points, and then interpolating the positions of pixels across the mesh to create a sequence of intermediate images. Each intermediate image represents a smooth transition where the appearance of the starting image morphs progressively towards that of the target image. This technique is not just about blending or crossfading but involves a detailed deformation of the entire image structure, making it useful in applications such as character animation, facial expression manipulation, and creating special effects in movies and digital art. Advanced algorithms ensure that the morphing process maintains spatial coherence and produces visually realistic results, making it a powerful tool for visual storytelling and creative expression in digital media.

**6.Implementation**

**Algorithm:**

**CODE:**

Fusion:

clc;

close all;

clear;

fusiontype='MinMin';

wavetype='coif5';

[filename1,pathname1]=uigetfile('\*.\*','select the 1st image');

filewithpath1=strcat(pathname1,filename1);

img1=imread(filewithpath1);

%Load image2

[filename2,pathname2]=uigetfile('\*.\*','select the 2nd Image’);

filewithpath2=strcat(pathname2,filename2); img2=imread(filewithpath2);

[row, col]=size(img1(:,:,1));

if ~ isequal(size(img1),size(img2))

img2=imresize(img2,[row,col]);

end

fusedimageR=imgfusion(img1(:,:,1),img2(:,:,1),fusiontype,wavetype); fusedimageG=imgfusion(img1(:,:,2),img2(:,:,2),fusiontype,wavetype); fusedimageB=imgfusion(img1(:,:,3),img2(:,:,3),fusiontype,wavetype); fusedimage=uint8(cat(3,fusedimageR,fusedimageG,fusedimageB));

imwrite(imresize(fusedimage,[row,col]),'fusedimage.jpg','Quality',100);

subplot(131)

imshow(img1)

title('Image1')

subplot(132)

imshow(img2)

title('Image2')

subplot(133)

imshow(fusedimage)

title('fused image')

Imagefusion:

%function to create fused image

Functionoutimage=imgfusion(Im1,Im2,ftype,wtype) [cA1,cH1,cV1,cD1]=dwt2(double(Im1),wtype,'per'); [cA2,cH2,cV2,cD2]=dwt2(double(Im2),wtype,'per');

[r,c]=size(cA1);

cA=zeros(r,c);

cH=zeros(r,c);

cV=zeros(r,c);

cD=zeros(r,c);

switch ftype

case 'MeanMean'

for i=1:r

for k=1:c

cA(i,k)=mean([cA1(i,k),cA2(i,k)]);

cH(i,k)=mean([cH1(i,k),cH2(i,k)]);

cV(i,k)=mean([cV1(i,k),cV2(i,k)]);

cD(i,k)=mean([cD1(i,k),cD2(i,k)]);

end

end

case 'MeanMax'

for i=1:r

for k=1:c

cA(i,k)=mean([cA1(i,k),cA2(i,k)]);

cH(i,k)=max([cH1(i,k),cH2(i,k)]);

cV(i,k)=max([cV1(i,k),cV2(i,k)]);

cD(i,k)=max([cD1(i,k),cD2(i,k)]);

end

end

case 'MeanMin'

for i=1:r

for k=1:c

cA(i,k)=mean([cA1(i,k),cA2(i,k)]);

cH(i,k)=min([cH1(i,k),cH2(i,k)]);

cV(i,k)=min([cV1(i,k),cV2(i,k)]);

cD(i,k)=min([cD1(i,k),cD2(i,k)]);

end

end

case 'MaxMean'

for i=1:r

for k=1:c

cA(i,k)=max([cA1(i,k),cA2(i,k)]);

cH(i,k)=mean([cH1(i,k),cH2(i,k)]);

cV(i,k)=mean([cV1(i,k),cV2(i,k)]);

cD(i,k)=mean([cD1(i,k),cD2(i,k)]);

end

end

case 'MaxMax'

for i=1:r

for k=1:c

cA(i,k)=max([cA1(i,k),cA2(i,k)]);

cH(i,k)=max([cH1(i,k),cH2(i,k)]);

cV(i,k)=max([cV1(i,k),cV2(i,k)]);

cD(i,k)=max([cD1(i,k),cD2(i,k)]);

end

end

case 'MinMax'

for i=1:r

for k=1:c

cA(i,k)=min([cA1(i,k),cA2(i,k)]);

cH(i,k)=max([cH1(i,k),cH2(i,k)]);

cV(i,k)=max([cV1(i,k),cV2(i,k)]); \

cD(i,k)=max([cD1(i,k),cD2(i,k)]);

end

end

case 'MinMin'

for i=1:r

for k=1:c

cA(i,k)=min([cA1(i,k),cA2(i,k)]);

cH(i,k)=min([cH1(i,k),cH2(i,k)]);

cV(i,k)=min([cV1(i,k),cV2(i,k)]);

cD(i,k)=min([cD1(i,k),cD2(i,k)]);

end

end

end

outimage=idwt2(cA,cH,cV,cD,wtype,'per')

**7.Result**

**7.1 Visual inspection**

Visual inspection in image fusion projects is crucial for evaluating the quality of fused images. It involves checking the clarity and sharpness to ensure that details from both original images are preserved without introducing blurring or loss of information. Color consistency is assessed to maintain natural color tones and ensure a seamless blend between images with different color profiles. Detecting artifacts such as noise, blur, or unnatural boundaries helps identify any imperfections introduced during the fusion process. The inspection also focuses on how well important features and structures are integrated and preserved in the fused image, ensuring it accurately represents the combined information. Ultimately, visual inspection considers both objective metrics and subjective preferences to validate the effectiveness of the fusion technique in achieving the desired outcome for the project.

**7.2 Quantitative evaluation**

Quantitative evaluation in image fusion projects is essential for objectively assessing the quality and performance of the fused images. Several key metrics are commonly used to measure different aspects of the fusion process.

Peak Signal-to-Noise Ratio (PSNR) is a widely-used metric that quantifies the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Higher PSNR values indicate better quality, suggesting that the fused image closely matches the original images in terms of pixel values and overall appearance.

Structural Similarity Index (SSIM) measures the similarity between two images based on luminance, contrast, and structure. It produces a value ranging from -1 to 1, where 1 indicates perfect similarity. SSIM is valuable for evaluating how well the fused image retains the structural information and textures present in the original images.

Mutual Information (MI) quantifies the amount of information shared between images. Higher MI values indicate better alignment between the fused image and the originals in terms of shared information content. This metric is particularly useful for assessing how effectively the fusion process integrates complementary details from multiple source images.

Entropy is another metric used to measure the randomness or unpredictability of pixel intensity values in the fused image. Lower entropy values suggest that the fused image has higher information content and less redundancy, indicating a more efficient fusion process.

Fusion Quality Index (FQI) combines multiple metrics such as PSNR, SSIM, and entropy to provide an overall assessment of fusion quality. It offers a comprehensive evaluation by considering various aspects of image fidelity and information preservation.

These quantitative metrics complement visual inspection by providing numerical benchmarks to objectively evaluate the effectiveness of image fusion algorithms. They help researchers and practitioners gauge how well the fusion process integrates information from multiple sources while preserving image quality and minimizing artifacts.

**7.3 Output images**

**8.Discussion**

**8.1 Advantages**

Image fusion provides significant advantages across diverse fields and applications. One of its primary benefits is the enhancement of information content by integrating data from multiple sources or modalities. This process enriches the overall dataset, offering a more comprehensive view of the scene or subject under observation. By combining information from different sensors or imaging techniques, image fusion improves the quality of the resultant images. It reduces noise, enhances spatial or spectral resolution, and brings out finer details that may not be discernible in individual images alone. This improvement in image quality facilitates clearer and more accurate interpretation and analysis.

Furthermore, image fusion enhances human perception by presenting a more coherent and complete representation of the scene. It aids in decision-making processes by providing clearer insights and improving understanding. The integration of data from multiple modalities allows for a holistic view, which is particularly valuable in applications where a comprehensive understanding of complex environments or situations is crucial.

Image fusion also enables the integration of information from different imaging modalities, such as optical, infrared, and radar. This capability supports diverse applications ranging from remote sensing and medical imaging to surveillance and environmental monitoring. By combining complementary data, image fusion techniques can extract and highlight specific features or patterns that may be obscured in individual images. This feature extraction capability is essential for tasks like object detection, recognition, and classification.

Moreover, image fusion contributes to efficiency in data handling and processing. By consolidating multiple sources into a single image, it reduces the volume of data that needs to be stored, transmitted, or processed. This efficiency is beneficial in fields where real-time processing or large-scale data management is required.

Overall, the versatility, efficiency, and capability of image fusion techniques make them indispensable in modern applications across various domains. They enhance image quality, facilitate better understanding and decision-making, and enable advanced analysis and interpretation of visual data, ultimately leading to improved outcomes in numerous practical scenarios.

**8.2 challenges**

Image fusion, while offering numerous benefits, presents several challenges that researchers and practitioners must navigate. One significant challenge is the precise registration and alignment of images from different sensors or modalities. Variations in viewpoint, resolution, and calibration between sources can lead to misalignment, which in turn may introduce artifacts or degrade the quality of the fused image. Ensuring accurate registration is crucial to maintain the integrity and fidelity of the fused data.

Assessing the quality of fused images poses another challenge. While quantitative metrics like Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) provide objective measures, they may not fully capture perceptual quality or the relevance of fused information to specific applications. Balancing these metrics with qualitative assessments and applicationspecific requirements remains a complex task.

Choosing an appropriate fusion method for a given application is also non-trivial. Different techniques, such as wavelet transforms, multi-resolution analysis, or deep learning approaches, have distinct strengths and limitations depending on the data characteristics and objectives of the fusion task. Selecting the optimal method involves understanding these trade-offs and selecting the approach best suited to the specific requirements.

Handling heterogeneous data is another challenge in image fusion. Integrating information from sources with varying resolutions, spectral bands, or noise characteristics requires robust techniques capable of effectively combining and enhancing data while preserving critical features. Ensuring compatibility and coherence across different types of input data is essential for achieving meaningful fusion results.

Moreover, the computational complexity of advanced fusion techniques can be prohibitive in real-time applications or environments with limited resources. Methods involving multi-resolution analysis or deep learning models may require significant computational power, posing challenges in deployment and scalability.

Artifact mitigation is another critical issue. Fusion processes can introduce artifacts such as noise, blur, or discontinuities at the boundaries of fused regions. Minimizing these artifacts without compromising image quality is essential for ensuring accurate interpretation and analysis of the fused images. Furthermore, the subjectivity in evaluating fused images adds complexity. While quantitative metrics provide objective assessments, human perception and application-specific requirements may influence the interpretation of fusion quality. Addressing these subjective elements while maintaining rigorous evaluation standards is crucial for ensuring the effectiveness and reliability of fusion techniques.

Finally, ensuring the adaptability and robustness of fusion techniques across different environmental conditions and sensor characteristics remains a persistent challenge. Techniques must be capable of delivering consistent performance and maintaining reliability amidst variations in input data quality or operating conditions.

Navigating these challenges requires ongoing research, innovation, and interdisciplinary collaboration across fields such as image processing, computer vision, and remote sensing. Addressing these hurdles is essential for advancing the capabilities and applicability of image fusion in diverse domains, including remote sensing, medical imaging, surveillance, and environmental monitoring.

**8.3 potential improvement**

Improving image fusion techniques involves several key areas of development to enhance their effectiveness and applicability across various domains. One critical area is the advancement of fusion algorithms. Research into more sophisticated algorithms, such as deep learning-based approaches and adaptive fusion methods, can significantly enhance the ability to handle diverse data sources and complex scenes. These algorithms can autonomously select and fuse information from multiple sensors or modalities, optimizing the fusion process based on specific application requirements and environmental conditions.

Additionally, enhancing the integration of information from multiple modalities is essential. Developing techniques that seamlessly combine data from optical, infrared, radar, and other sensors can provide a more comprehensive and nuanced understanding of the scene or object being observed. This integration allows for richer data analysis and more accurate decisionmaking in applications ranging from remote sensing to medical imaging and beyond. Improving registration and alignment techniques is another critical area for advancement. Precise registration of images from different sources mitigates misalignment issues that can lead to artifacts or degraded image quality in the fused result. Robust registration methods that account for variations in viewpoint, resolution, and sensor characteristics are essential for maintaining the fidelity and accuracy of fused images.

In terms of evaluation, advancing quality assessment metrics beyond traditional measures like Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) is crucial. Developing metrics that better capture perceptual quality, relevance to specific applications, and suitability for human interpretation can provide a more comprehensive evaluation of fusion performance. These metrics can help researchers and practitioners better understand how well fused images meet practical needs and application-specific requirements.

Efforts to optimize fusion algorithms for real-time processing capabilities are also essential. Developing efficient algorithms that can operate in real-time or near real-time is critical for applications requiring rapid decision-making, such as surveillance or emergency response scenarios. Optimization techniques, including hardware acceleration and parallel computing, can improve algorithmic efficiency and reduce processing time without compromising accuracy or quality.

Artifact reduction techniques represent another area ripe for improvement. Implementing advanced methods for noise suppression, edge enhancement, and artifact mitigation can enhance the visual quality and interpretability of fused images. Techniques that minimize artifacts while preserving critical details are crucial for ensuring accurate analysis and reliable decision-making based on fused data.

Moreover, integrating machine learning techniques within the fusion process holds promise for enhancing information extraction and utilization. By leveraging machine learning for feature learning, classification, and pattern recognition tasks within the fusion framework, researchers can automate and optimize data analysis processes. This integration enables more advanced and intelligent applications of fused imagery in fields such as object detection, classification, and anomaly detection.

Lastly, addressing privacy and security considerations in image fusion applications is essential. Developing techniques for secure fusion, data anonymization, and access control helps mitigate risks associated with sensitive or confidential data. Ensuring robust privacy protections enhances trust and facilitates the responsible deployment of image fusion technologies across various sectors. By focusing on these areas of improvement, researchers and practitioners can advance the capabilities of image fusion techniques, making them more robust, efficient, and applicable across a wide range of domains and practical applications.

**9.Conclusion**

In conclusion, implementing image fusion using Discrete Wavelet Transform (DWT) in MATLAB offers a robust methodology to enhance and integrate information from multiple source images effectively. Through the decomposition process using dwt2, each image is broken down into approximation (LL) and detail (LH, HL, HH) coefficients, capturing both low-frequency components and high-frequency variations. Selecting an appropriate fusion rule, such as averaging or maximum selection, allows for the combination of corresponding coefficients from decomposed images. This fusion process aims to preserve essential details while reducing noise and artifacts, resulting in a fused image that integrates the most relevant features from the original sources. The final step involves using the idwt2 function to reconstruct the fused image, ensuring a seamless integration of enhanced information suitable for applications in image processing, analysis, and interpretation. By leveraging DWT's capabilities, MATLAB facilitates the creation of composite images that are enriched with comprehensive visual and structural information, tailored to meet specific project objectives and enhance decision-making processes in various fields.

**10.Future work**

Future advancements in image fusion are poised to revolutionize various fields by addressing current limitations and exploring new capabilities. One promising area of research involves enhancing multi-modal fusion techniques. Future efforts will focus on integrating data from diverse sources such as optical, infrared, and radar sensors to provide a more comprehensive understanding of complex environments and scenarios. This approach aims to leverage the strengths of each modality to overcome challenges like poor visibility or incomplete information in individual sensor outputs.

Deep learning is another frontier for image fusion, with ongoing exploration into advanced neural network architectures. Future work will delve deeper into leveraging deep learning models for adaptive feature extraction, learning complex relationships between input data sources, and improving the accuracy and efficiency of fusion processes. These efforts are expected to yield more robust and adaptable fusion algorithms capable of handling diverse and dynamic data inputs.

Real-time processing capabilities represent a critical area for future development. Researchers will continue to optimize image fusion algorithms for speed and efficiency, particularly for applications requiring rapid decision-making or embedded systems. This includes exploring techniques for hardware-accelerated implementations and parallel computing to ensure reliable performance in resource-constrained environments.

Advancing quality assessment metrics is also essential to ensure the reliability and effectiveness of image fusion techniques. Future research will focus on developing new metrics that better align with human perception, incorporate application-specific requirements, and provide comprehensive evaluations of fusion performance across different domains. These metrics will play a crucial role in guiding algorithmic improvements and validating the practical utility of fused images.

Adaptive fusion strategies will continue to evolve, aiming to dynamically adjust fusion parameters based on environmental conditions, data characteristics, and user preferences. Future research will explore autonomous optimization algorithms that enhance fusion performance and adaptability in diverse operational scenarios. These strategies will enable more responsive and efficient utilization of fused data in real-world applications.

Improving artifact reduction techniques and image enhancement capabilities remains a priority. Future work will focus on developing advanced algorithms for noise suppression, artifact mitigation, and enhancement of critical image details. These efforts aim to minimize distortions introduced during the fusion process while enhancing the visual quality and interpretability of fused images.

Integration of machine learning techniques within image fusion processes holds promise for advancing data analysis capabilities. Future research will explore innovative applications of machine learning for feature extraction, pattern recognition, and semantic understanding of fused imagery. This integration will enable automated and intelligent processing of fused data, unlocking new insights and applications across various domains.

Addressing privacy and security concerns associated with image fusion technologies will be increasingly important. Future work will focus on developing robust techniques for secure data fusion, ensuring data confidentiality, integrity, and access control in sensitive applications. These efforts will support the responsible deployment and adoption of image fusion technologies in privacy-sensitive sectors.

Ultimately, future advancements in image fusion will benefit from collaborative research efforts and interdisciplinary approaches. By fostering collaboration between experts in image processing, computer vision, remote sensing, and related fields, researchers can tackle complex challenges and drive innovation in image fusion technologies. These efforts will pave the way for transformative applications in fields such as healthcare, environmental monitoring, agriculture, and autonomous systems, among others.

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