INFRARED AND VISIBLE IMAGE FUSION USING HYBRID LWT AND PCA METHOD

A DISSERTATION

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CANDIDATE'S DECLARATION

I Urvashi Rawat student of M.Tech (Signal Processing and Digital Design), hereby declare that the project dissertation titled "Infrared And Visible Image Fusion Using Hybrid LWT and PCA Method" which is submitted by me to the Department of Electronics and Communication Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any degree, diploma associate ship, fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project dissertation titled "Infrared And Visible Image Fusion Using Hybrid LWT and PCA Method" which is submitted by URVASHI RAWAT, 2K19/SPD/21 of Electronics and Communication Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this University or elsewhere.

Place: Delhi **Asst Prof. Sudipta Mujamdar**

Date: 30/ 08 /2021 **SUPERVISOR**

To My Parents,

Mrs. Ganga Rawat & Mr. B.S Rawat

And

My Mentor

Dr. Sudipta Majumdar

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ABSTRACT

Image fusion is a method in which all the relevant information is collected from the input source images and included in few/single output image. Image fusion techniques are divided into two broad categories: spatial domain and transform domain. Principal component analysis (PCA) is a spatial domain technique which is computationally simpler and reduces redundant information but has the demerit of spectral degradation. Lifting wavelet transform (LWT) is a transform domain technique which has an adaptive design and demands less memory. In this project, a novel hybrid fusion algorithm has been introduced which combines the LWT and PCA in a parallel manner. These two fusion methods are applied on Infrared and Visible image data set. Infrared and visible images contain complementary information and their fusion gives us an output image which is more informative than the individual source images. The hybrid method is also compared with conventional fusion techniques like PCA, LWT and DWT. It has been shown that the proposed method outperforms the conventional methods. The results are analyzed using performance parameters standard deviation, average value, the average difference, and normalized cross-correlation.

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LIST OF ABBREVIATION

IF	Image Fusion
VIS	Visible
IF	Infrared
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
SD	Standard Deviation
AD	Average Difference
NCC	Normalized Cross Correlation
AV	Average Value

CHAPTER 1

INTRODUCTION

1.1 Image fusion

Image Fusion [1] represents a method for enhancing the data performance from a given image collection. With help of image fusion, the better/relevant data from individual given input image is fused into a resulting image of a greater quality than the original images. A number of operations are carried out for the given input images, which will enhance the prominent information in both of the images. The output image is then obtained by combining the data from the given input images. There are a variety of applications for image fusion such as fusing medical images like magnetic resonance imaging (MRI)[2], electro-encephalographic (EEG), computed tomography(CT) [2], positron emission tomography(PET)), electrocardiographic imaging (ECG), in surveillance[3], object tracking, face recognition[5] and in remote sensing[4] etc. Fig. 1 shows the visible and infrared images and their output fused image, similarly fig. 2 ang fig. 3 shows the medical images and images obtained in surveillance respectively.

The image fusion can be widely divided into transform domain and spatial domain [1]. The spatial domain approaches include fusion methodologies such as the Brovey method, averaging, select minimum/maximum, principal component analysis (PCA) and IHS forms of methods. In these methods, the fusion algorithm is applied directly on the pixels of the input images. They are simple in terms of computation but the resulting image suffers distortion and lacks spatial information. The transform domain techniques on the other hand divide the input image to lower and higher frequency components thus providing us with details of the image and line/edge information. Some of the transform domain techniques are Discrete wavelet transform (DWT), stationary wavelet transform (SWT), lifting wavelet transform (LWT), complex contourlet transform (CCT), discrete cosine transform(DCT), non-subsampled shearlet transform (NSST) and nonsubsampled contourlet transform NSCT etc.

In this project, Infrared (IR) and Visible (VIS) [3][12] images have been selected for the fusion purpose. Although there are many types of images available for fusion, IR and VIS images have complementary aspects which when fused together, yield a better image. The IR image captures the thermal radiation of the object and hence the target detection ability of this image is commendable. VIS image captures the light reflected from the target, i.e in normal visibility conditions, it would provide us with a detailed image. Due to these reasons, motivation for finding a new algorithm which would enhance the quality of the output fused image arises.

Fig 1: From left to right- VIS Image, IR Image and Fused image

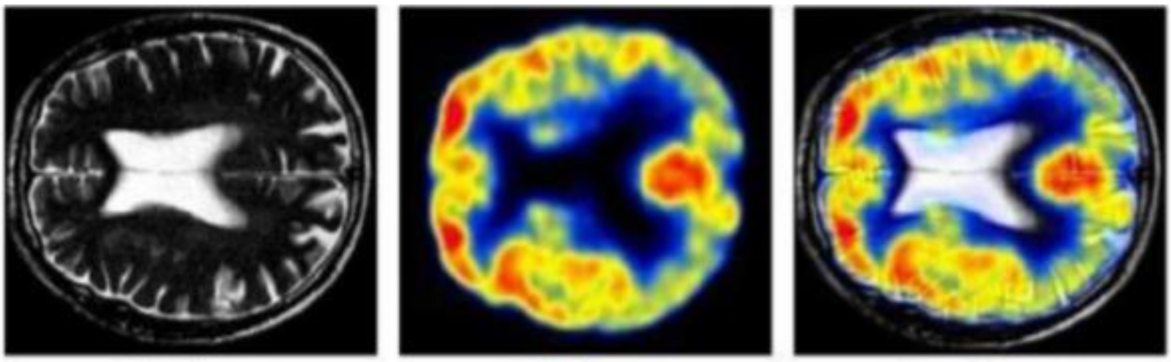

Fig 2: From left to right- MRI image, PET image and Fused image

Fig. 3: From left to right- Multi-spectral image, Panchromatic image and fused image

1.2 Necessity of Image Fusion

In the recent past, with technology advancing at a rapid rate, multi sensor fusion of image has become an area where no applications need more general formal solutions[26]. There are many circumstances in the processing of images that involve high spectral and spatial information obtained in a specific frame. For remote sensing applications, this is really important. But, either by design limitations or due to observational constraints, the equipment/devices are not able to provide us with such knowledge. IF is also one of the possible solutions to this problem. From study of the literature, it is observed that number of research paper in the field of IF has increased at an exponential rate[27] from the year 2011 to 2020. This is due to the demand for best quality images obtained by the method of fusion. Fig. 4 depicts a bar graph which illustrates the number of research papers which are published over these years in this domain.

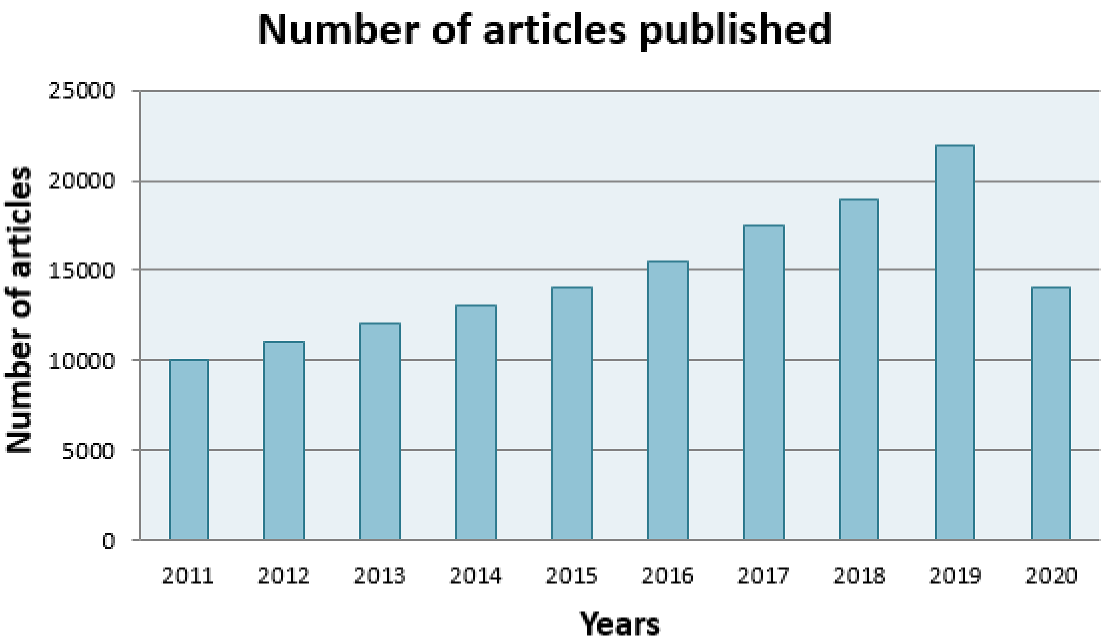

Fig. 4: Graph showing number of articles published over the years in image fusion

1.3 IR and VIS Images

IR images are those images which uses the IR radiations radiated by ta body. The IR sensor senses the temperature of the target[29]. If the temperature of the body is higher then we receive a strong IR spectrum, a brighter IR image and also a clear image[1]. It has a good target detection ability. But the demerit of IR image is that it has a low target resolution and a fuzzy background[28]. Also less details of the target are present. VIS images are those which uses the visible light reflected from the target and captured by a VIS light image sensor. These images have high spatial resolution and good contrast information. It also reflects the background. Edge details and structure details are present. But in case of low visibility conditions or poor weather conditions, the image quality becomes poor.

The low frequency coefficients of an image also called as approximate coefficients [13] contain the major information of an IF and VIS image. Most of the energy that is concentrated is in the lower frequency sub-bands. Whereas, the high frequency coefficients also called detailed coefficients contain the detailed information of the IR and VIS images[30]. This detailed information affects the clarity and resolution of the image. There have been many fusion rules which have been adopted for fusion of IR images with VIS images. In this project we have used the IR and VIS image dataset for enhancing the output fused image in terms of various parameters. Fig. 5 shows a simple example of fusion output of IR and VIS images.

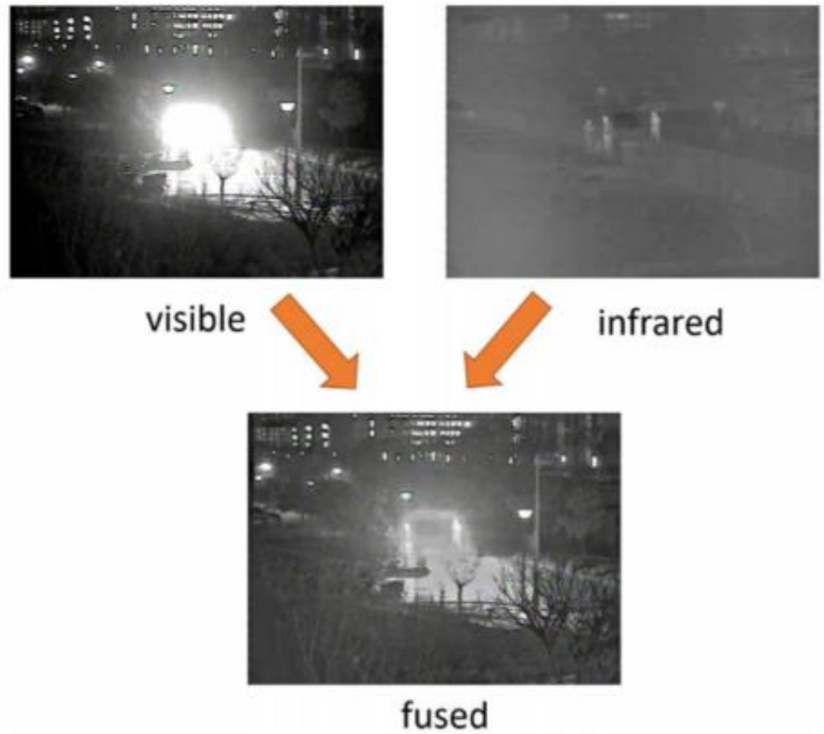

Figure 5: Fusion of IR and VIS image

1.4 Applications of Infrared and Visible Images

IR and VIS image fusion can be used depending upon our requirements. Some of the applications are listed below:

1. *Surveillance:* For the surveillance [5,6] application we require a clear and expressive image. IR and VIS images have complementary properties which make them a good choice for fusion. The IR image detects the thermal radiation of the object[31] and thus it is not affected by low visibility or bad weather conditions. However, the disadvantage of IR image is that it has low spatial resolution which causes less details in the image. On the contrary, the VIS images have high spatial resolution but easily affected by low visibility and weather disturbances. Thus fusion of these images improves visibility and help in surveillance application.

2. *Recognition:* Recognition is the method in which we specify the category of a particular target in an image which contains more than one objects[32]. One of the major application in the recognition using IR and VIS image is Face Recognition[7].

3. *Detection and Tracking:* IR and VIS-based fusion is employed in a variety of real-world detection applications, object detection[8], fruit detection, and pedestrian detection.Apart from these, the fusion method is also useful in target tracking in unmanned aerial vehicles.

4. *Color vision:* Only visible light can be perceived by the human eye[32]. Therefore the target image which is obtained by infrared radiation should be converted to images having pseudo colors.

5. *Other applications:* IR and VIS image fusion is also applied in other fields such as remote sensing[6], augmented reality and culture relic analysis re relic analysis.

1.5 Organization of the Report

The rest part of the report is consisting of the following sections. Chapter 2 contains the literature review of some of the techniques in either spatial, transform or hybrid methodology which have been implemented recently. Then chapter 3 discusses about the various image fusion techniques of spatial domain and transform domain in detail. The proposed work is explained in chapter 4 and the results of the experiments and performance parameters are explained in chapter 5. The paper is concluded in chapter 6 along with future work which can be done in the image fusion domain as further research. Finally, the references are listed.

CHAPTER 2

LITERATURE REVIEW

In 2016, K. Padmavathi, M. V. Karki and M. Bhat[6] developed a method for fusing the medical images with PCA and complex wavelet transform (CWT)[35]. It combined the advantages of shift-invariance of CWT and feature enhancement of PCA. The proposed algorithm proved to be better in representing the spatial details and soft tissues of the tumor. Analyzing and comparing the method using Peak signal-to-noise ratio (PSNR) [36], fusion factor and entropy, it was found that the proposed method outperformed other methods of fusion.

In 2016, the authors Saranya G and S. N. Devi [7] used several methods like DWT, PCA, SWT, NSCT and CCT for fusion of medical images. The result of the methods were analyzed using mutual information (MI) and it was found that CCT method had more MI than the other methods [37]. It was suggested that the proposed algorithm could be used in future for diagnosis purposes in medical field.

In 2016, a new method which was based on combination of framelet transform, PCA and DCT was introduced by P. Sharma, P. Kulkarni, H. Sanghvi and A. Verma[8]. The method inherited the merits of DCT, PCA and framelet domain[70]. The proposed method was compared with some conventional techniques and it was concluded that, improved results were achieved with regard to mean square error (MSE) [38], PSNR and visual look analysis.

In 2017, A. A. Mergin and M. S. G. Premi[9] introduced a hybrid method for medical signal fusion. The EEG and ECG signals were fused and then reconstructed using hybrid DCT-DWT method. This method proved to be better that the individual DWT and DCT in terms of PSNR which indicated a achievement of better signal reconstruction.

In 2017, authors B. L. Priya and K. Jayanthi[10] presented a technique for fusion which enhanced the edge information of CT image of the Abdomen. The method was based on NSST which gave better results in segmentation accuracy of liver. The proposed method showed improvement segmentation accuracy of 60.11% in terms of similarity index.

In 2018, M. B. Abdulkareem[11] performed fusion of the MRI image and PET images using the haar wavelet approach. The proposed algorithm was tested on brain images of Alzheimer's disease and the input images were decomposed at four levels of high and low frequency regions. The fused image's quality was tested using the PSNR and MSE. This method gave 90-95% accuracy.

In 2018, the authors S. M. Nemalidinne, A. P. Sindhu and D. Gupta[12] presented a fusion method for IR and VIS fire images using NSCT which was based on the pulse coupled neural network and Gabour energy. This proposed method was better with regards to high visual quality and high entropy when were compared to the conventional methods. The NSCT method[68] has shift-invariance and provides with multi-scale decomposition.

In 2019, N. Taxak and S. Singhal[13] described a method for fusion using the Weighted Average and Brovey Transform. The fused image had good clarity, increased PSNR value and decreased MSE value than the other fusion techniques like PCA, DWT, DCT.

In 2019, A. Yehia, H. Elhifnawy and M. Safy[14] introduced a method for fusion of multi sensor images integrating IHS and SWT transform method. Initially SWT of the input image was taken which preserved the spectral information and then it was combined with IHS algorithm. This method gave favorable results concerning spectral and spatial information. Two different types of fusion rules were chosen which are: average method and window-based fusion.

In 2019, V. Brindha. and P. Jayashree [15] introduced a fusion method for the Glioblastoma Multiforme images. The fusion methodology included the weighted average method and maximum selection of the enhanced DWT. The method was demonstrated to be better than some of the existing techniques in terms of fusion quality.

In 2019, J. R. Benjamin and T. Jayasree[16] introduced a methodology for fusion of multimodal brain images. The authors used NSST method and used the Maximum rule as fusion method. Two types of data set of the MRI image and PET images [67] were used. The proposed method proved to be better in terms of edge details, correlation and information preservation.

In 2020, M. Saayadi, H. Ghasemian, R. Naimi and M. Imanii [17] introduced a fusion method in which the NSST was used as an edge detector, to match the luminance channel of MRI image with PET image, IHS transform was applied on PET image A gaussian filter was also applied in order to get the low resolution intensities. The final fused image was obtained by integrating the two images and then taking inverse HIS transform. This method proved to be better in terms of preserving the spatial information and having less spectral distortions than the other methods.

In 2020, T. Tyagi, P. Gupta and P. Singh[18] introduced a novel method which combined the PCA and SWT techniques in a parallel manner to yield better results for multi focus images. The hybrid methodology gave satisfactory results than the conventional methods with respect to PSNR and correlation coefficient.

In 2021, Kaur, H., Koundal, D. & Kadyan [19] presented a paper on various image fusion techniques. Different spatial and transform domain techniques were discussed with their merits and demerits. Apart from this, different applications of image fusion like remote sensing, medical image, surveillance[66] etc. were also discussed. At last, evaluation metrics were also discussed for evaluation of the fusion techniques.

CHAPTER 3

Study and Analysis of the Image Fusion Techniques

The IF techniques are narrowly divided into two types which can also be seen in fig. 6:

(i) Spatial-Domain Fusion

(ii) Frequency-Domain Fusion

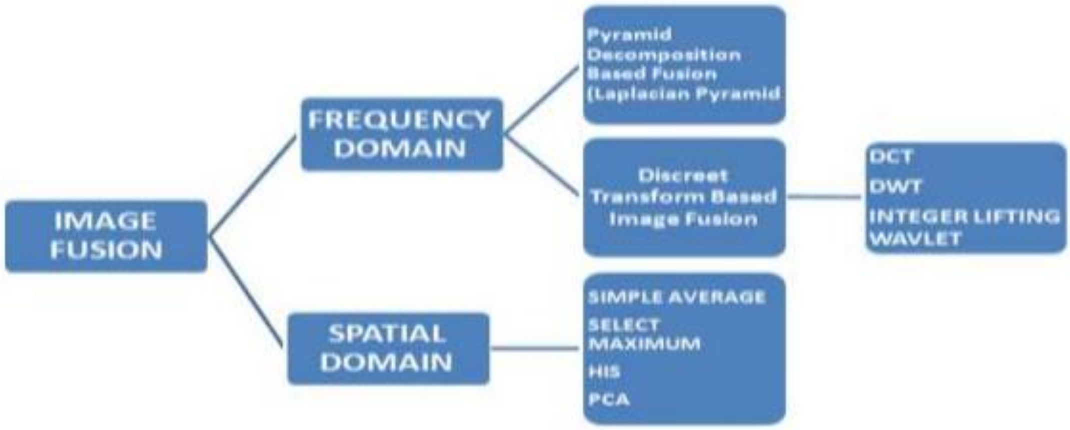

Fig. 6: Image fusion methods based on 'spatial' and 'frequency' domain

The spatial domain methods/approaches include fusion methodologies such as the Brovey method, averaging, PCA and IHS forms of methods[39]. Image Fusion's high pass filtering method is another very important spatial-domain fusion technique. The 'higher frequency' information were incorporated in the up-sampled part of the images in this process. Demerit of this domain algorithm/approach is the production of the 'spatial distortion' in the output image [65] which is fused. Thus this becomes a matter of concerns while we proceed further for processing, eg: classification problem[40]. The 'Spatial distortion' problem can be solved perfectly by the 'frequency domain' methodology to Image Processing. In remote sensing, multi-resolution measurement for fusion purposes has become an effective tool. The ‘discrete wavelet transform’(DWT) is one such frequency domain technique[64] which has become popular tool for fusion purposes. Some other techniques can be classified as: method 'Laplacian pyramid,' method 'Curvelet transform,' etc. Compared to the previously explained spatial domain process, these frequency domain techniques demonstrate better performance in terms of 'spatial distortion' and 'spectral distortion.

3.1 Spatial domain techniques

Fig. 7 shows the block diagram of spatial domain image fusion methodology.

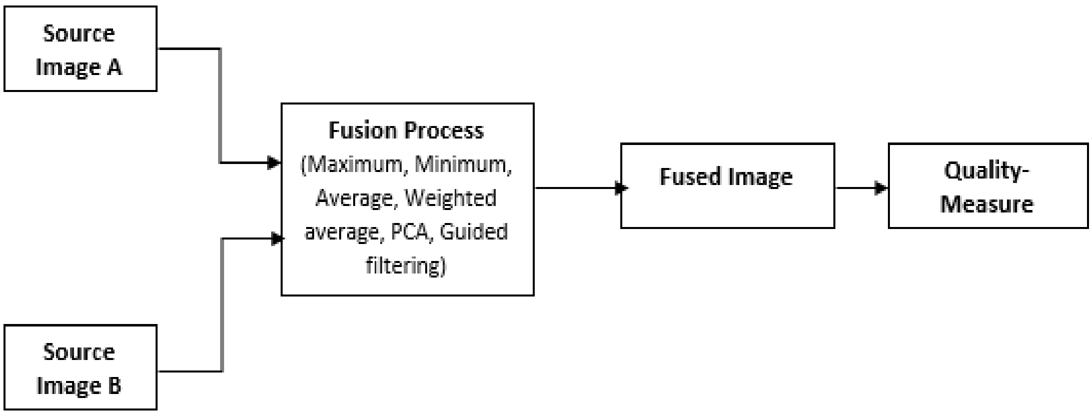

Fig. 7: Spatial domain fusion

Image Fusion Methods in Spatial Domain

For spatial domain, the algorithm of fusion is applied directly to the image’s pixels of input IR and VIS images[40]. This method is computationally simpler but lacks spatial information and output images suffer from distortion, contrast loss and also information loss.

1. *Minimum Method*

The input images are obtained and then compared in this technique. Pixel having lower value is then selected. This is a simple technique which is easy to implement and understand [64] but the fused image suffers from poor contrast and is blurred[41]. Due to this, minimum method is not suitable for real life applications.

2. *Maximum Method*

This method is quite close to the IF minimum method. The difference is that the maximum pixel value is selected as the output pixel value. This method is also not suitable for IR and VIS image since poor contrast is present[9].

3. *Simple average*

In this method, as the name suggests we simply obtain the average of the pixel values of two input images i.e we add the pixel value of given images and then divide by the number of input images[42]. The input images that needs to be fused are taken from the similar kind of sensors and they must have high contrast and brightness. This method is easy to comprehend and execute. The output obtained by the average is then assigned to the pixel corresponding to the output image[63]. Likewise this can be done to all other pixel values of the input images.

The formula for pixel averaging can be given as:

$$Y(u,v) = \frac{X1(u1,v1)+X2(u2,v2)+\cdots Xn(un,vn)}{n}$$

Where Y(u,v) is the output image obtained, $X1(u1,v1) + X2(u2,v2) + \cdots Xn(un,vn)$ are input image and the term ‘n’ is the no. of input images.

4. *Weighted average*

The weighted average[2] of the intensity of corresponding pixels is taken from both the input image and the final fused image is derived using this method. This strategy aids in the improvement of detection accuracy.

$$P(x,y)= \sum_{x=0}^{m} \sum_{y=0}^{n} WU(x,y) + (1-w)V(x,y)$$

Here W is called the weight factor, U(x,y), V(x,y) are represented as the input images and P(x,y) is representing the output image.

5. *IHS*

IHS can be described as a colour space. “Hue” is defined as the predominant wavelength of any colour. “Saturation” can be defined as the total amt. of white light of any colour. “Intensity” is defined as amt. of light reaching the human eyes [42]. IHS could be used in Radar system with different kinds of data like Landsat TM, thematic data etc. The aim of fusion of multispectral and high resolution remote sensing images is to ensure spectral information while still adding high spatial resolution detail information. As a result, the fusion is much more suitable for treatment in IHS space.

6. *Brovey Method*

The Brovey method is based on the chromaticity transform [43]. It's an easy but effective method for integrating data from various sensors. The spatial knowledge of the PAN image is well preserved by the Brovey. However, in this approach, spectral information distortion is not suitable.

7. *Principal Component Analysis(PCA)*

PCA is a technique that employs the orthogonal transformation technique [62] to create a new image with all of the properties of the previous images and two main dimensions referred to as principal components[44]. It’s mostly used for feature extraction and dimensionality reduction. It reduces redundant information and has high spatial quality[11]. But the fused image has color distortion and spectral degradation.

8. *Guided Filtering*

The guided filtering[12] method is translation variant, and has advantages of edge-preserving smoothing. Guided filters have been used in a variety of fields, including IR and VIS imaging. In computer vision applications such as noise reduction, haze removal, and smoothing, a guided filter is more effective.

3.2 Transform domain techniques

In the transform domain, input images are first divided into lower frequency and higherr frequency components in the transform domaiin[45]. The details of image are provided by the lower frequency components while the line and edge information of the image is provided by the high frequency components. Below, the block diagram of transform domain technique is shown in fig.8.

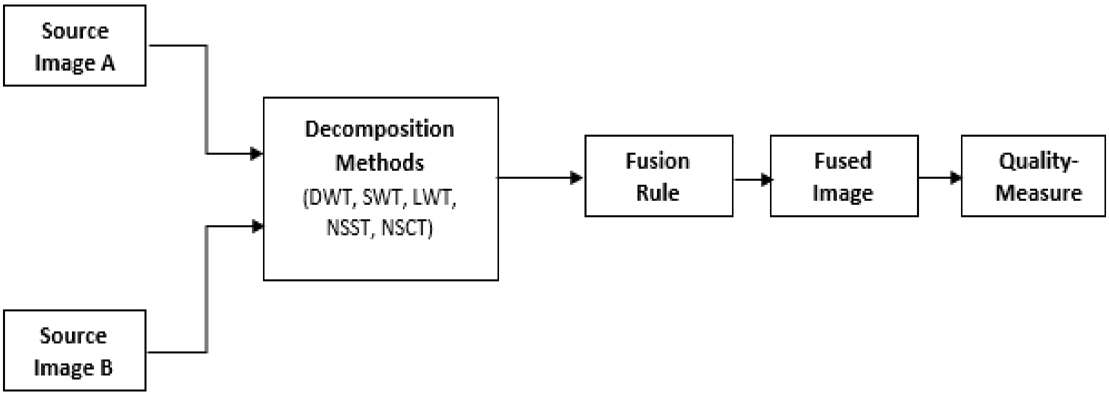

Fig. 8: Transform domain fusion

1. *Discrete Wavelet Transform*

The given source IR and VIS images are split into higher frequency and lower frequency coefficients through the use of the Discrete Wavelet Transform[13] (DWT) as shown in fig. 9. The lowest frequency band represent the approximation information and t The detailed information is represented by bands with high frequencies.. This method is better that the spatial domain techniques[2] because it gives the output image having high signal to noise ratio and low spectral distortion. Also it minimizes the color distortions and provide better resolution. However, DWT has the issue of shift variance and oscillations and also lacks directionality.

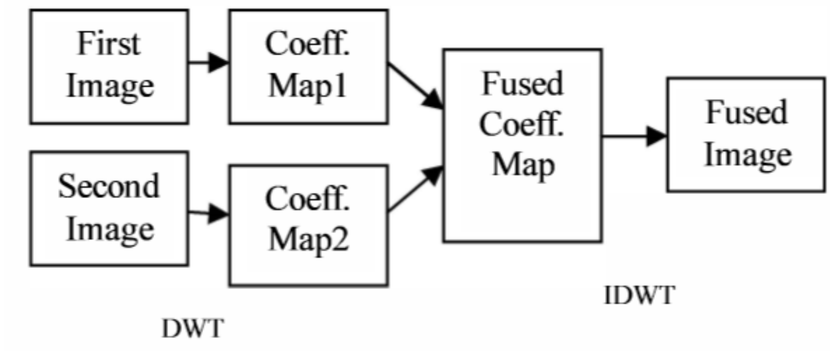

Fig. 9: DWT based image fusion

2. *Lifting Wavelet Transform*

In Lifting wavelet transform(LWT) wavelet transform the total number of samples at each stage is similar to the total number of samples at the start[46]. It is quite alike to the DWT.

To get approximation and detailed coefficients, the input samples are divided into even and odd sets and afterwards processed via the filters. Because the approximation coefficients can be obtained at a certain stage from the information coefficients previously computed and some of the input samples, the number of computations involved is also reduced. In terms of Fusion factor and Fusion symmetry, LWT is superior[14]. The Lifting scheme replaced the wavelet transform in terms of less memory and hardware requirements. However, it doesn’t have shift-invariance and the output fused image has Gibbs Effect and distortion.

3. *Stationary Wavelet Transform*

The DWT approach suffers from translation invariance, which is overcome by the Stationary Wavelet Transform (SWT)[47]. It decomposes the source image’s important feature by multi-resolution analysis. It is called a redundant technique since at each level of output same number of samples are present as the input. SWT proves to be better since it can be applied to any random sized image and the image might not necessarily be of size two’s power. This method truncates zeros in filter while upsampling and suppresses while downsampling step in DWT.

4. *Non subsampled Contourlet Transform*

The non-subsampled contourlet transform (NSCT) [16] is a two dimentional tool for decomposition and analysis of the image derived from Contourlet transform (CT). The CT method of fusion had problems of shift variance, poor frequency selection and Gibbs phenomenon. The NSCT eliminates the upsampling and downsampling operation[48] of CT therefore this method is said to have shift-invariance, also it ensures good frequency selectivity. The NSCT algorithm also reduces the effect of misregistration and Gibbs phenomenon. In IR and VIS image fusion, this approach is commonly utilized [17].

5. *Non-Sampled Shearlet Transform*

In order to overcome the demerits of Shearlet transform[16], NSST method was introduced. It has many decomposition directions due to which it possess multi- direction and translation invariance. In NSST method of fusion, non-subsampled pyramid filter bank is cascaded with shearing filter bank[49]. It is shift invariant and can extract edge texture of the input images.

6. *Pyramid transform*

The pyramid transformation concept was suggested in the year 1980. In this approach, the levels of the pyramids are fused using an appropriate fusion rule which are obtained after the down sampling step of the input source images. The fused image output can then be obtained by reconstructing the fused image pyramid. After 1980, many pyramid transforms have been introduced and have been extensively used in IR and VIS image fusion domain, et al., Laplacian [34], steerable [37], and contrast [50] pyramids. The advantage of this method is that this method is useful in providing information regarding changes in sharp contrast.

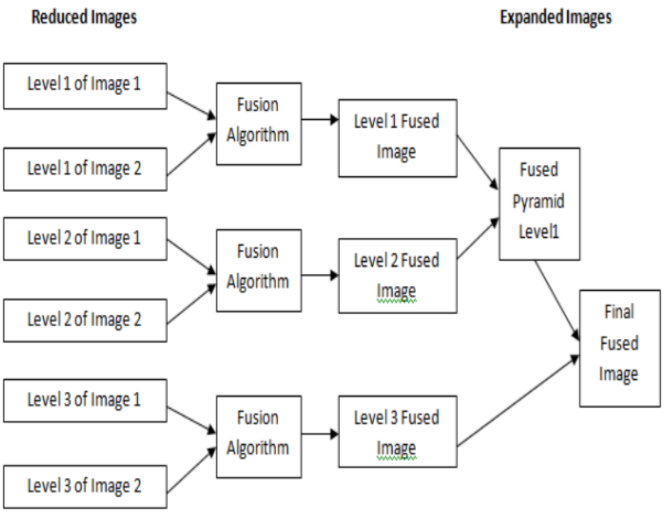

Fig. 10: Block diagram of pyramid based image fusion

A. *Laplacian Pyramid*

The transformation from the Laplacian pyramid method needs successive iterations of (a) low pass filtering, (b) interpolating and then (c) differencing. Author Bulanon et al. used the Laplacian pyramid transform method along with the fuzzy logic for fusion of IR and VIS image data of fruits [32]. This method proved to be better for detection performance of fruits when compared to just using IR image [50].

B. *Steerable Pyramid Transform*

The original image is broken down into a subimage group in different dimensions and directions using the method of steerable pyramid transform. This method provides with the merits of rotational invariant, self-inverting, translational and non-aliasing properties[42]. Liu et al. introduced a method for fusion of images using the steerable pyramid method along with the expectation maximization algorithm. This proposed method was able to outperform the conventional method of fusion i.e steerable pyramid method [36].

C. Contrast Pyramid

The transform method of contrast pyramid is derived from the laplacian pyramid method. In this method we calculate the ratio of the two low pass filtered image of Gaussian pyramid method that are adjacent. This method is capable of considering the local contrast [51]. Author Jin et al. introduced a method for IR and VIS image fusion which was multi-objective evolutionary method which was used for optimization of the fusion coefficients and contrast pyramid method.

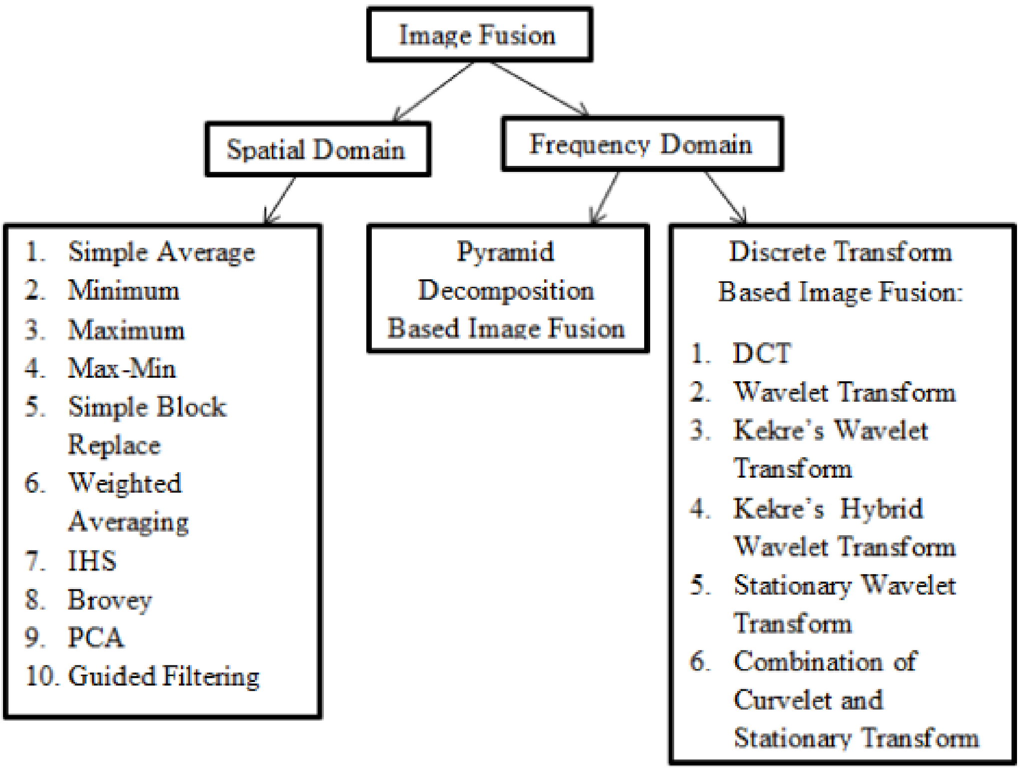

Fig. 11: Various fusion methodologies

The table 1 below shows the comparison of various spatial and transform domain techniques.

Fusion methods	Advantages	Disadvantages
	Spatial Domain	
Simple Minimum [9]	Simple method, easy to implement and understand	Output is blurred, poor contrast, Not preferred for real life applications
Simple Maimum [9]		
Average method [2]		Noise is introduced, reduced contrast, low image quality
Weighted Average [2]	Detection reliability is improved	Poor contrast
PCA [10,11]	Reduces redundant information, high spatial quality	Spectral degradation and color distortion
Guided Filtering [12]	Edge preserving smoothening, translational variant	
IHS Method	Simple approach, high spatial quality.	Suffers from artifacts, color distortion and noise.
	Transform Domain	
Discrete Wavelet Transform[13]	Provides better resolution	Shift variance present, lacks directionality, problem of oscillation
Lifting Wavelet Transform[14]	Adaptive design, irregular sampling	Gibbs effect, shift variance present
Stationary Wavelet Transform[15]	Preserves edge information, and image texture	Weak in case of continuous region, time consuming, image represented only in three directions
Non-Subsampled Contourlet Transform[16,17]	Flexible, shift-invariant, faster implementation	Complicated structure, computation cost is high
Non-Sampled Shearlet Transform[16]	Multi-directionality, preserves edges and curves	Weak for subtle image features
Laplacian/Gausian pyramid	It offers a superior image quality for multi-focused images	Number of decomposition levels effect the results of IF

.

Table 1: Comparison of Spatial and Transform domain techniques

CHAPTER 4

Proposed Work

4.1 Related theories

4.1.1 Principal Component Analysis

The PCA technique is used for feature extraction. It is also well known Karhunen–Loève transform. The main task of “principal component transform (PCA)” is transform a correlated set of data to an orthogonal set of variables called as principal components [52]. The principal components can be refered as ‘linear combinations’ of the observed variables which are optimally weighted .

In PCA, the number of components which are extracted are equal to the number of variables observed which are analyzed.

However, in most PCA analyses, there is only the largest variance for the first of the few components, therefore only the first few are kept for interpretation and further analysis purposes.

Let’s take:

Y – as a ‘D’-dimensional random vector

(assume empirical mean=0)

V - as the projection matrix

(such that X =VTY)

the constraints are given as follows,

cov (X)- covariance of X

where the diagonal of V and inverse of V are equivalent to their transpose value (V-1=VT))

By using the matrix algebra,

$$cov(X) = E\{XXT\} \quad (1)$$

$$cov(X) = E\{(YVT)(VTY)T\} \quad (2)$$

$$cov(X) = E\{(YVT)(VYT)\} \quad (3)$$

$$cov(X) = VT\ cov(Y)V \quad (4)$$

On muItiplying L.H.S and R.H.S of the equation (4) by the projection matrix V, following equation is obtained,

$$Vcov(X) = VVT\ conv(Y)\ V = conv(Y)\ V \quad (5)$$

Now after substituting the equation number (4) in the equation number (5) we get,

$$[\Upsilon 1V1, \Upsilon 2V2, \Upsilon 3V3.. \Upsilon dVd] = [conv(X)V1, conv(X)V2, .., conv(X)Vd] \quad (6)$$

We can re-write the equation as:

$$\Upsilon i\ Vi = cov(Y)\ Vi \quad (7)$$

Where, i =1, 2, ... , d

Vi is the eigen-vector of the cov(Y).

Flow Diagram

The diagram shown below is a flow-diagram of IF method using PCA technique.

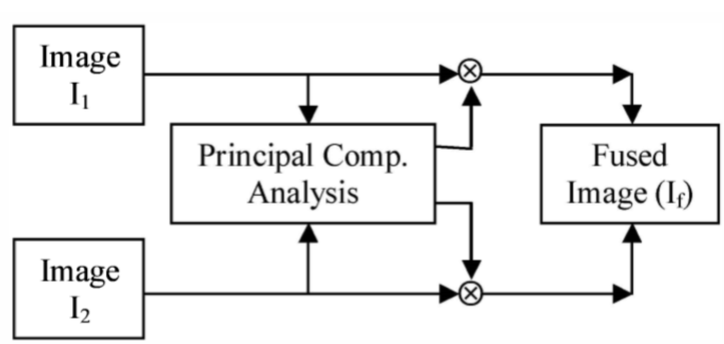

Fig. 12: Flow diagram of Principal Component Analysis

As can be seen, the input images are initially organised in 2 columns and the empirical mean subtracted from them. The generated vector has a n x 2 dimension where n is the vector length of each image. The eigen vectors and the eigen values for the resulting vector are then calculated [53]. The eigen vectors are calculated according to the larger eigen values after this stage.

Then the normalised L1 and L2 components from the acquired vector are computed. The output fused image is represented by the following equation:

$$If(x,y)= L1I1(x,y)+L2\ I2(x,y) \quad (8)$$

PCA Algorithm

Take the image sources, i.e. images arranged in two-column vectors that are to be fused together. The measures to be taken to project the knowledge into 2-D subspaces are now as follows:

Step 1: First we arrange the details into the column vectors. The Z matrix resulting will have a dimension -[2 x n].

Step 2: Next we calculate the empirical mean Me along each of the columns. Dimensions Me will be 1 x 2.

Step 3: Now we subtract Me (Me vector) from columns of the S (data matrix). Then the final resulting matrix Y will be of the dimension [2 x n].

Step 4: Next we go on to finding the covariance matrix C of the Y matrix i.e. C=YYT

“mean of expectation” = cov(Y)

Step 5: Calculate the 'V' and 'D' eigen values of the 'C' matrix and arrange them into decreasing eigen values. The dimensions of both V and D are [2x2].

Step 6: Take now the first 'V' column that corresponds to a greater own-value for LI and L2 computing as follows, L1 = $\frac{V(1)}{\sum V}$ and L2 = $\frac{V(2)}{\sum V}$

Advantages of PCA

- PCA has Fast Processing Time.
- It has high Special Quality.

Disadvantages of PCA

- Spectral degradation.
- Colour distortion.

4.1.2 Lifting Wavelet Transform

The LWT based fusion divides the image in one low frequency component and three high frequency component. The lower frequency parts are known as a coefficient of approximation while the higher frequency coefficients are called the detailed coefficients, which are horizontal, vertical and diagonal. [21]. This decomposition method can be applied as many times. After the decomposition is done, the coefficients of original input images are merged by using an appropriate rule for fusion. The new fused coefficients also contain four coefficients. After that, Inverse LWT (ILWT) is applied to get the final fused image. The LWT block diagram is shown in Fig.2 and Fig.3. It can be subdividednto three steps viz split, predict and update [22,54].

(1) Split: The original image is split into two mutually disjoint sets S1, D1. Often the signal is splitted into odd and even sequence i.e S1 represents low frequency components and D1 represents high frequency components.

$$\text{Split}(S0)=(\text{Even}1,\text{Odd}1)=(S1,D1) \quad (9)$$

(2) Predict: The subset S1 is utilised to forecast sub-set D1 for the removal of repeated data. This is done to reduce computation and storage. Use P, the prediction operator so that a the original dataset 'S0' is expressed as subset of S1, let D1 = P (S1). 'D1 reflects degree of approximation between D1 and P(S1), and includes fewer information than D1. Therefore, in order to

reduce the storage, we can represent original signal in terms of ' D1 and S1. Prediction can be represented as:

' D1= D1- P（S1） (10)

(3) *Update:* After prediction, it might be possible that coefficient produced by S1 might not align with the original source image. Therefore updation is required to maintain the original characteristics of the data[68]. We can generate a much better subset of '1S' with the U operator in order to retain specific properties of dataset S1.The updating can be expressed as follows:

S1’ =S1+U(' D1) (11)

In the same way, three steps above can be used for the subset S1, i.e. the S1 divided to D2 and S2. After decomposing n times, the original S0 data set can be described in {Sn, Dn,Dn -1,...,D1}, in which Sn is a low frequency component of the signal and Dn are high frequency components.

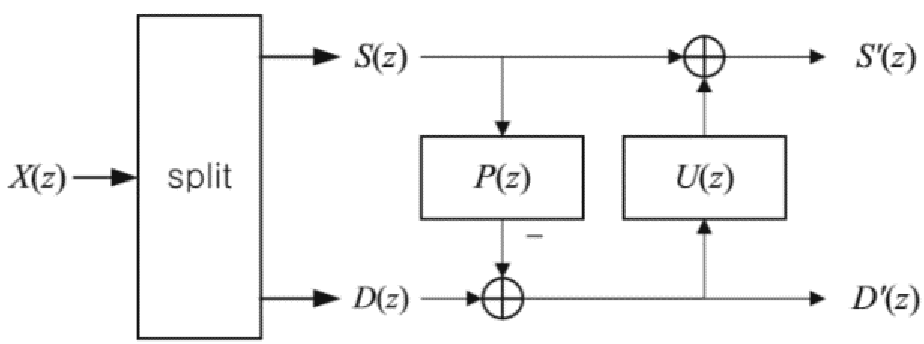

Figure 13: Lifting operation

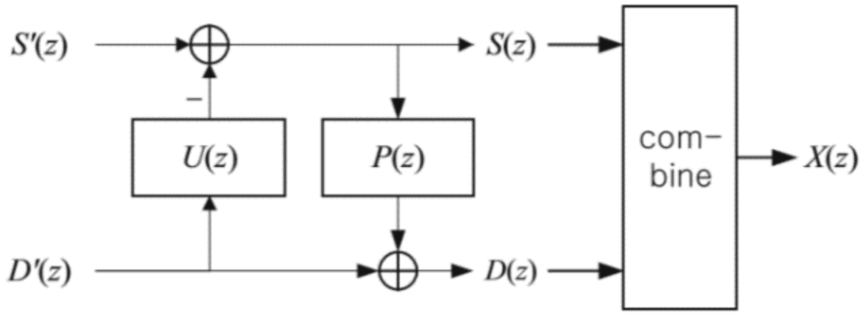

Figure 14: Inverse lifting operation

Reconstruction of LWT method

The reconstruction process of LWT is the exact inverse of the decomposition process. There are three steps as follows:

(1) Inverse update: S1= ' 1 S -U (' D1) (12)

(2) Inverse predict: D1= ' D1+P (S1) (13)

(3) Merge: S0=Merge (S1, D1) (14)

In the merge step, even and odd sequences i.e S1 ans D1 are combined to original signal S0.

Image Fusion procedure based on the Lifting Wavelet Transform

If there are 'n' decompositions of a 2-D image, then the number of sub-bands will be '3n+1'. Out of these 3n+1 sub-bands, 3n will be the high frequency or detailed coefficient and 1 will be the low frequency or approximate coefficient [55]. The steps involved in lifting method are described below:

(1) Take the input images and conduct one dimension transform in both of them. From this step, we will receive detailed and approximate coefficients. After that, we will perform another one dimension transform on the approximate coefficients which will further give us 3 high frequency components and 1 low frequency components[72].

This step is repeated as many number of times we desire depending on the requirement.

(2) Now we fuse the obtained decomposed coefficients according to a suitable fusion rule.

(3) At last, in order to get the final fused image, we apply inverse lifting transform is on the coefficients obtained in the step 2.

Image Fusion Rule

To get a high quality fused image, it is essential to apply an appropriate fusion rule needs to be applied. After we perform 2 D lifting wavelet on the input image, we obtain three detailed coefficient images and one approximate coefficient image[56]. Both these kind of images have different kind of information, therefore we need to apply different fusion rules to the different coefficients.

(1) *Approximate coefficient fusion*The source image's average grey information and the texture information are contained in this frequency. This frequency focuses the most of the energy of the source image. Since the human eye is more sensitive to the lower frequency hence average method of fusion has been adopted in this project in order to enhance and maintain the structural information of the source image.

(2) *Detailed coefficient fusion*: It contains the information on the source image and the source image edge. since it depicts the edge information of the image, therefore we apply selection of the maximum value[57] so that important edges are preserved in the fused image. If lowest values were selected then it would weaken the prominent edges.

4.2 Framework of Proposed Approach

In this proposed work, the two input images are processed in a parallel manner using two different type of fusion methods as shown in the block diagram Fig.15. The input images are IR and VIS image[71] as shown in Fig. 5 (a),(b) respectively. The steps of the proposed methodology are discussed below:

Step 1: LWT scheme is first applied on the input images which results in level-1 of decomposition. After this step, approximate coefficients LL1 and detailed coefficients LH1,HL1, HH1 are obtained.

Step 2: Level-2 decomposition is done again on the approximate coefficients LL1 to obtain LL2, LH2, HL2, HH2.

Step 3: The detailed part of the LWT contains maximum information, so it is important to get best of the two images. Therefore maximum rule is applied .

Step 4: The approximate part also holds some information but not much, therefore average rule is applied to them.

Step 5: The original IR and VIS images are also fused using the PCA based fusion method in parallel.

Step 6: Finally, both the fused images of LWT and PCA are combined to get the final output fused image.

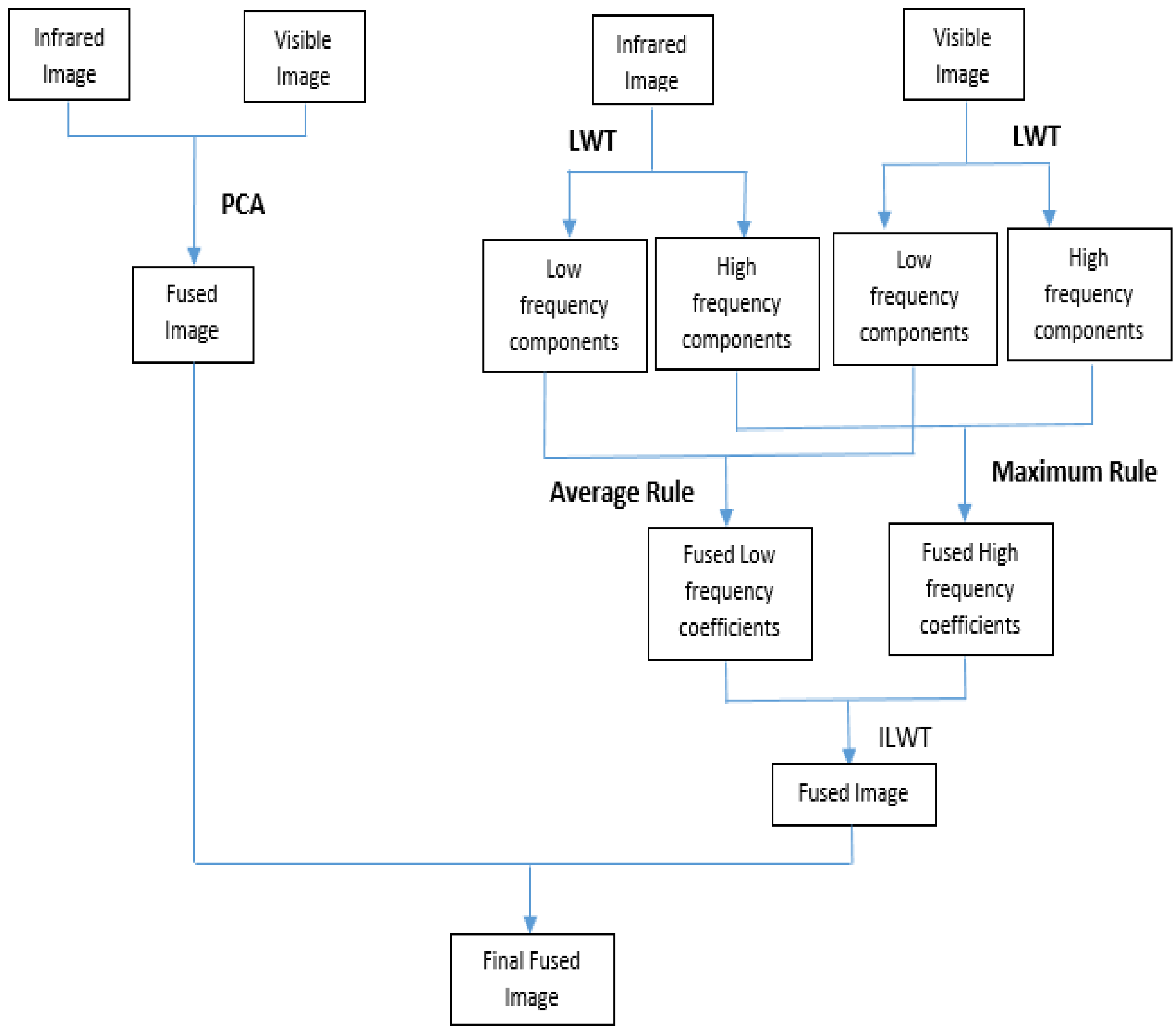

Fig. 15: Block diagram of proposed work

CHAPTER 5

Simulation Results and Performance Parameters

The proposed work was implemented in MATLAB 2017a and the dataset used is TNO data set, from which two different types of IR and VIS images have been taken. The Dataset 1 in fig. 16 (a), (b) is the ‘‘Bristol Queen’s road [58]’’ in which the person is visible in the IR image but lacks details. Whereas in VIS image the details are present but the person is not visible.. For quantitative analysis of the proposed method, various performance criteria are selected which are Standard Deviation (SD), Average Value (AV), Average Difference (AD) and Normalized cross correlation (NCC). The description of these performance parameters are provided in the Table 2.

Performance Parameters	Description
Standard Deviation[23]	Degree of dispersion between average pixel and single pixel of the image is given by SD.
Average Value[23]	Average brightness of the fused output image is described by AV.
Average Difference[24]	The difference between the fused image output and the original image is called AD.
Normalized cross correlation[24]	NCC provides similarities of output fused image with input image.

Table 2: Description of performance parameters

5.1 Performance Criteria

1. *Subjective Evaluation*

   For this evaluation the output image of all the fusion algorithms is provided and the major areas of focus have been highlighted to get a clear idea about the difference in the quality of images. However, subjective evaluation should be done when there is a significant difference between images. Therefore, objective evaluation should also be done to get accurate judgement[59] of different algorithms.

2. *Objective Evaluation*

   (i) Standard Deviation (SD)

   SD gives the degree of dispersion between average pixel and a single pixel[60] of the image. Larger value of SD means high contrast, more information and wide gray value distribution. The formula for the SD is given below.

$$SD = \sqrt{\frac{1}{M*N}\sum_{I=1}^{M} \sum_{i=1}^{N}(p(i,j) - \mu)^2} \quad (15)$$

where P(i, j) is gray value and μ is mean value of pixel at (i, j).

(ii) Average Value (AV)

The average brightness of the output fused image is defined by the parameter AV. A larger value of this parameter means brighter image is obtained[60,61]. The formula for AV is given below.

$$\mu = \frac{1}{M*N}\sum_{i=1}^{M}\sum_{j=1}^{N} p(i,j) \quad (16)$$

where P(i, j) refers to a fused image pixel where N is the image height and M is the image width..

(iii) Average Difference (AD)

AD represents the difference in the fused image and the original input image . This parameter must give lower values. The formula of AD is given below:

$$AD = \frac{1}{pq} \sum_{i=1}^{p} \sum_{i=1}^{q} |A\text{ij} - B\text{ij}| \quad (17)$$

(iv) Normalized Cross-correlation (NCC)

NCC provides similarities of output fused image with the original image. NCC should have a high value. The formula is given below:

$$\frac{\sum_{i=1}^{p} \sum_{i=1}^{q} (A\text{ij} * B\text{ij})}{\sum_{i=1}^{p} \sum_{i=1}^{q} (A\text{ij})^2} A = \pi r^2 \quad (18)$$

5.2 Results

The fusion of input IR and VIS images using the proposed method has also been compared to other conventional methods such as DWT, PCA and LWT. The result of these methods are listed in Table 3. For subjective analysis of the algorithms, the output images are shown in fig 16.

Fusion Methods	**SD**	**AV**	**AD**	**NCC**
PCA	48.96	81.33	3.05	1.01
DWT	22.77	91.09	6.70	0.97
LWT	23.50	91.13	-6.74	0.97
Proposed method	67.22	163.14	-88.07	1.98

Table 3: Quantitative Analysis

From the experimental analysis, it was found that the proposed method had a higher value of SD, NCC and AV i.e 67.22, 1.98 and 163.14 respectively which is greater than the conventional fusion methods used for comparison. Also, the performance of the novel method was analyzed using AD performance criteria and it was found that this value came out to be less in case of the proposed method, which proves to be better since the difference between fused image and input image should be as less as possible.

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 16: (a) input IR image, (b) input VIS image, output images using (c) DWT, (d) PCA, (e) LWT, (f) Proposed method

CHAPTER 6

Conclusion and Future Scope

In this project, a parallel fusion method for IR and VIS image dataset was introduced using LWT and PCA. At first, the LWT 2 D decomposition was applied to the input images. The obtained approximate coefficients were fused using the average method and the detailed coefficients were fused using the maximum selection rule, ILWT was applied after that step. The fusion of input images was also d one using the PCA method in parallel. The method included fusion of the input images in a parallel manner. The final fused images obtained from both the methods were fused together to get the final output image. The image obtained from the proposed method was compared with conventional methods PCA, DWT, and LWT using AD, SD, AV, and NCC and it was found that the new method gave better results in these parameters. The future work focuses on extending this novel hybrid fusion algorithm to medical images so that better quality of the output image can be obtained .

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