Fusion of Multi-focus Images using Spatial-scale based Techinques: Application to Feature Identification

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Abstract
This paper demonstrates the usefulness and performance of spatial-scale based techniques in the field of multi-focus image fusion for feature identification. Spatial-scale based image fusion techniques overcome the limitation of the conventional Fourier-based, purely Spatial and Frequency based methods. Further, spatial-scale based techniques provides description of local spectral properties of non stationary image at different scales which is requisite for multi-focus image fusion. The spatial-scale based image fusion techniques, namely, Discrete Wavelet Transform (DWT), Stationary Wavelet Transform (SWT) and Non Sub-sampled Contourlet Transform (NSCT), have been selected for the fusion of multi-focus images. The accuracy of image fusion methods has been evaluated by using Correlation Coefficient (CC) and Universal Image Quality Index (UIQI), Peak Signal-to-Noise Ratio (PSNR) and Root Mean Square Error (RMSE). Experimental results exhibit that the NSCT based image fusion technique not only take out more important ocular information from source images, however, also efficiently evade the introduction of synthetic information. It notably better than the established SWT and DWT based fusion technique in terms of feature identification.

Keywords- Image Fusion, Spatial-scale, Stationary Wavelet Transform, Non Sub-sampled Tranform.

1. *Introduction*

Due to the restricted depth-of-focus of optical lenses in CCD devices, it is frequently not possible to capture an image that contains all relevant features 'in focus'. One possible solution to prevail over this problem is to utilize the multi-focus image fusion techniques, in which several images with unlike focus points are pooled to form a single image with all objects fully focused [2]. During the fusion process, all the important qualitative information found in the input images must be incorporated into the fused image without introduction of artifacts i.e. the fusion technique should be consistent and robust to defects [1–3]. Further, image fusion concept has been extended to many applications [3]–[5].

Over the years, a number of techniques for multi-focus image fusion have been proposed, belongs to different categories, such as spatial and transform based technnique [4]. However, many researchers have recognized that spatial-scale based techniques are very useful for image fusion perspective [6–10]. The basic idea of such technique is to perform a MST on each source image first, and then employ some fusion rules to construct a composite multi-scale representation of the fused image. The fused image is finally reconstructed by taking an inverse MST. The commonly used spatial-scale techniques include the Discrete Wavelet Transform (DWT) and many more [7–10]. Further, DWT has many advantages in terms of localization and direction which is required for a good fusion [9, 11].

However, it is found that DWT suffers from poor directionality and the lack of shift invariance due to aliasing between sub-bands. These limitations can be overcome by using some of DWT's extensions, such as the Stationary Wavelet Transform (SWT) which is translation invariant [11]-[13]. It is observed that SWT offers limited directional selectivity i.e., it does not resolve the problem of feature orientation. Thus, to resolve the limitation of DWT and SWT, Non Sub-sampled Contour-let Transform (NSCT) has introduced [14-16]. This method possess the property of shift-invariance, multi-directionality and spatial-scale based local characterization of image representation. The remarkable properties of NSCT motivate its use in image processing applications, such as, edge detection, image fusion, etc.

Thus, the main objective of this study is to evaluate the comparison of performance of DWT, SWT and NSCT image fusion techniques for the fusion of multi-focus images used for feature identification.

2. An overview of image fusion methods

The MST techniques which are selected for this study are DWT, SWT and NSCT.

2.1 DWT based Image Fusion

In the DWT algorithm, the Low Pass (LP) and High Pass (HP) filters have been used for the decomposition of image. These filters divides the image into two bands i.e., LP and HP bands [5-6]. The former performs an averaging operation to extract the average information of the image, whereas, the later performs an differencing operation to extract the lines, points and edges information. Thereafter, the output of filtering operation is decimated by 2. A 2-D transformation is achieved by performing two individual 1-D transforms, along row and column separately [7-10]. This operation decompose the image into four bands namely LL, LH, HL and HH respectively.

2.2 SWT based Image Fusion

In order to resolve the problem of shift-variance associated with DWT, SWT based de-noising technique has been introduced [11-13]. In SWT, the filter is up-sampled by adding zeros between the coefficients, thereby excluding the down-sampling step. In SWT, filter bank have been used for the decomposition of image, which in turn produces an approximation image and a detailed image, also called the wavelet plane. A wavelet plane contains the horizontal, vertical and diagonal information between 2^j and 2^{j-1} resolution. Further, the approximation image consist of equal number of rows and columns as the original image. This is due to the fact that the filters at each stage are up-sampled by adding zeros between the coefficients, which makes the size of the image equal [12-13].

2.3 NSCT based Image Fusion

[15] proposed a novel method known as, NSCT, to overcome the impact of frequency aliasing of contourlets. NSCT possess the property of shift-invariance and multi-directionality, which is required for the effective analysis of an image, particularly for image de-noising. In addition, it provides enhanced frequency selectivity and uniformity over CT. Further, it consists of two filter banks one is Non Sub-sampled Pyramid Filter Banks, provides multi-scale decomposition and other is Non Sub-sampled Directional Filter Banks, provides directional decomposition, which is used to divide Band Pass sub-bands in each scale into different directions [14-16].

The general fusion procedure for the multi-focus image fusion using MST techniques can be recapitulate as follows (Figure. 1):

i) Perform a DWT/SWT/NSCT on each source images, one by one, to get their corresponding coefficients.

ii) Obtain coefficients form the different source images are combined using defined fusion rule, to get the fused coefficients.

iii) Apply Inverse DWT/SWT/NSCT technique reconstruction with new fused coefficient to obtain the fused image.

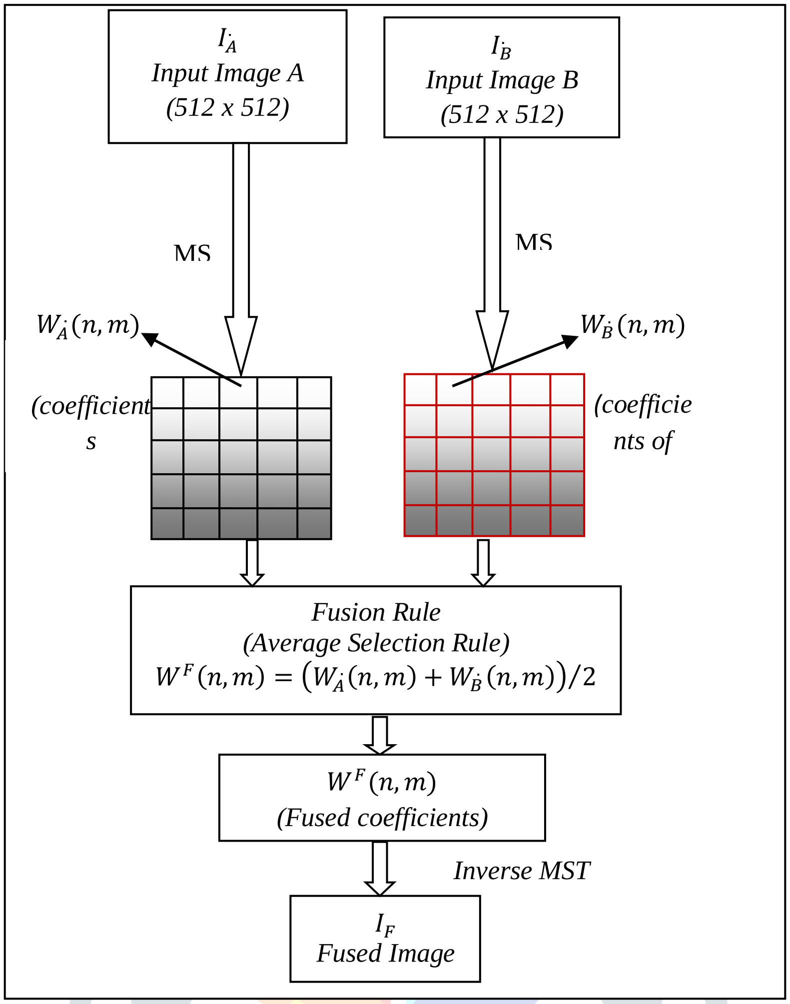


Figure 1: Methodology adopted for DWT, SWT and NSCT based image fusion.

Here, the fusion rule used in this study can be defined as follows

i.Average Fusion Rule (AFR)

The AFR takes the average of the coefficients of the image A, ($W_{\dot{A}}$) and image B, ($W_{\dot{B}}$) images is given by (Eq. 1).

$$W^F(n,m) = (W_{\dot{A}}(n,m) + W_{\dot{B}}(n,m))/2 \quad \text{... (1)}$$

3. *Evaluation Criteria*

Quantitative metrics have been used for the assessment of generated fused images other than simple qualitative assessment of the fused images [17-20]. The mathematical representation of these measures, such as RMSE, PSNR, CC and UIQI have been discussed below:

i) Root Mean Square Error (RMSE)

RMSE is one of the most usable, accurate and effective metric for the estimation of quality of image when reference image is available [18-20].

$$RMSE = \sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\left(F(i,j) - R_o(i,j)\right)^2}{M \times N}} \quad \text{... (2)}$$

where, M, N indicate the size of the image is $M \times N$. $F(i,j)$, $R_o(i,j)$ indicate the fused and refrence image. With smaller RMSE, there is less difference between them.

ii) *Peak Signal-to-Noise Ratio (PSNR)*

PSNR is one of the most well-known full reference metric, used to quantify the deformation of the generated fused image. The value of PSNR should be large for better output [20].

$$PSNR = 10log\left(\frac{255}{RMSE}\right)^2 \quad \ldots (3)$$

iii) Correlation Coefficient (CC)

The CC of two images is often used to indicate their degree of correlation between the original image and the fused image. For a good correlation between the images, the value of CC must approaches one [20-21]. The correlation coefficient is given by

$$corr(x,y) = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(x(i,j)-\overline{x})(y(i,j)-\overline{y})}{\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n}(x(i,j)-\overline{x})^2 \sum_{i=1}^{m}\sum_{j=1}^{n}(y(i,j)-\overline{y})^2}} \quad \ldots (4)$$

where $x(i,j)$ and $y(i,j)$ the elements of fused and original image, respectively. $\overline{x}$ and $\overline{y}$ stand for their mean values.

iv) Universal Image Quality Index (UIQI)

[22] proposed a method to model any image distortion via a combination of three factors: loss of correlation, luminance distortion, and contrast distortion [21-22]. The mathematical representation of UIQI is given below:

$$\mathrm{UIQI} = \frac{\sigma_{xy}}{\sigma_x\sigma_y}\,\frac{2\overline{xy}}{(\overline{x}^2+\overline{y}^2)}\,\frac{2\sigma_x\sigma_y}{(\sigma_x^2+\sigma_y^2)} \quad \ldots (5)$$

For a good fusion of images assessed, the following conditions must be satisfied (Table 2).

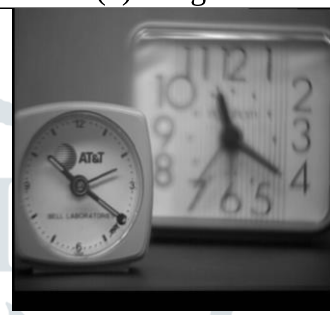
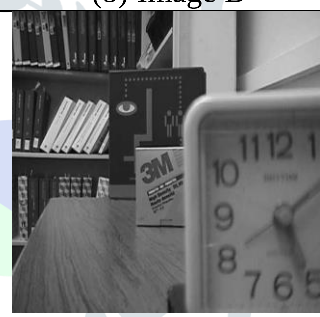
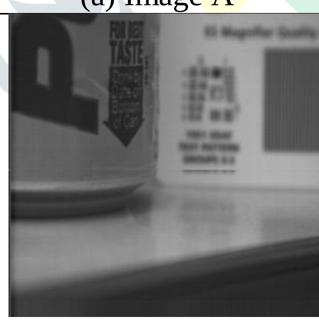
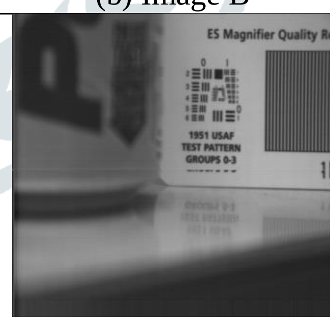
Table 1 The ideal and error value of different metrics

S. No.	Metric	Ideal Value	Error Value
1	RMSE	0	> 0
2	PSNR	NA	> 1
3	CC	1	> -1 and < 1
4	UIQI	1	> 0 and < 1

4. *Evaluation of Results and Discussion*

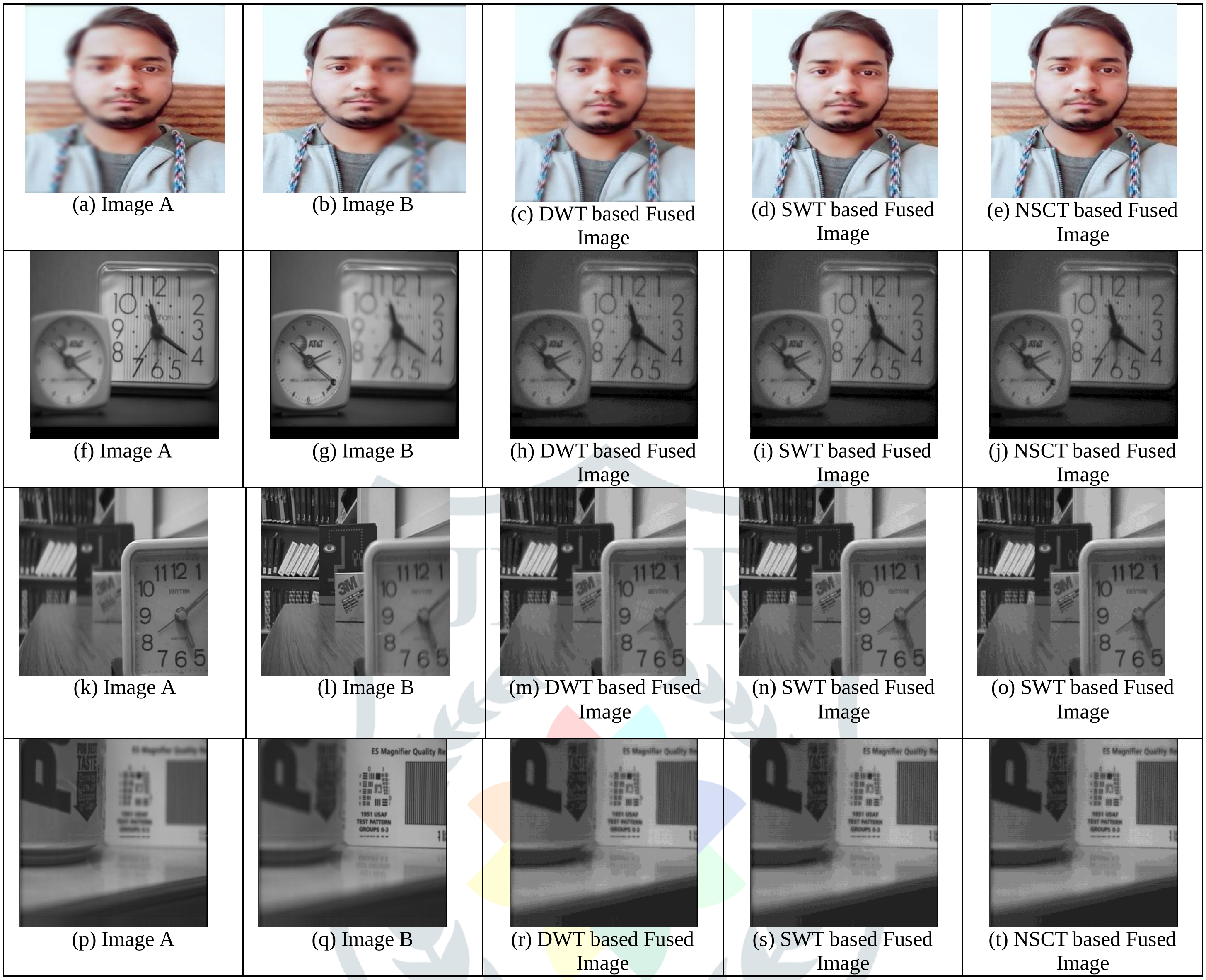
The selected fusion techniques have been evaluated using three multi-focus datasets acquired from CCD cameras, as shown in Table 1. Datasets corresponding to different focus angle, orientation and shape and size have been preferred, in order to examine the performance and suitability of fusion process.

Table 1: Data used

Dataset	Multi-focus Images	
DS-I	 (a) Image A	 (b) Image B
DS-II	 (a) Image A	 (b) Image B
DS-III	 (a) Image A	 (b) Image B
DS-IV	 (a) Image A	 (b) Image B

4.1 Visual analysis

A visual comparison of the fused images is used for the visual assessment for showing the major advantages and disadvantages of a fusion technique. In this study, the comparison of performance of the selected spatial-scale based image fusion techniques have been carried out for different multi-focus camera images (Figure. 2).



(a) Image A; (b) Image B; (c) DWT based Fused Image; (d) SWT based Fused Image; (e) NSCT based Fused Image
(f) Image A; (g) Image B; (h) DWT based Fused Image; (i) SWT based Fused Image; (j) NSCT based Fused Image
(k) Image A; (l) Image B; (m) DWT based Fused Image; (n) SWT based Fused Image; (o) SWT based Fused Image
(p) Image A; (q) Image B; (r) DWT based Fused Image; (s) SWT based Fused Image; (t) NSCT based Fused Image

Figure 2: Fusion results for different fusion techniques for different datasets.

Different parameters are used to evaluate the fused images visually. These parameters are listed below:

1. Colour Radiometry (CR)
2. Shape of the feature (SF)
3. Edge-Sharpening (ES)

Further, the fusion techniques have been scored 5 to 1, corresponding to their visual quality, as shown in Table 2.

Table 2 Evaluation of quality of image by qualitative method

Absolute Measure	**Relative Score**
Excellent (E)	5
Good (G)	4
Above Average (AA)	3
Average (A)	2
Poor (P)	1

Table 3 Comparison of fusion techniques on the basis of visual feature detection

Dataset	Fusion Rule	Fusion Method	CR	SF	ES
DS-I	AVG	DWT	2	2	2
		SWT	3	3	3
		NSCT	4	3	4
DS-II		DWT	2	2	3
		SWT	3	3	3
		NSCT	4	3	4
DS-III		DWT	2	2	3
		SWT	3	2	3
		NSCT	4	2	4
DS-IV		DWT	2	2	3
		SWT	2	3	3
		NSCT	4	3	4

With reference to Figure.2 and Table 3, it is found that fused images generated using NSCT (Fig. 2((e), (j), (o) & (t))), based fusion techniques yields better result visually when to compared to SWT (Fig. 2((d), (h), (n) & (s))), and DWT (Fig. 2((c), (h), (m) & (r))), based fusion techniques. In other words, it is observed that the geometrical information of all the fused images has improved when compared to the original image.

However, the fused image obtained by DWT, yields lower spatial quality. This is due to sub-sampling process and limited directional selectivity in DWT, which in turn results in false information as well as deteriorate the geometry of the features in the fused images.

Thus, it can be inferred that the NSCT image fusion technique using AFR works well in terms of feature identification by preserving the spatial and spectral information, followed by SWT and DWT based image fusion techniques for the same rule.

4.2 Quantitative analysis

The results of the various parameters of accuracy assessment for the fused images generated by different fusion techniques for different datasets has been discussed below.

Table 4 Statistical values for different fusion techniques

Dataset	Technique	PSNR	RMSE	CC	UIQI
DS-I	DWT	26.419	8.579	0.890	0.928
	SWT	28.457	6.472	0.902	0.942
	NSCT	29.542	6.096	0.924	0.956
DS-II	DWT	29.894	6.113	0.912	0.932
	SWT	30.710	5.857	0.935	0.935
	NSCT	30.921	5.732	0.956	0.938
DS-III	DWT	28.448	9.262	0.931	0.927
	SWT	29.807	8.240	0.936	0.945
	NSCT	31.124	7.923	0.930	0.930
DS-IV	DWT	29.609	6.152	0.946	0.942
	SWT	31.618	4.881	0.955	0.956
	NSCT	29.894	6.113	0.958	0.959

4.2.1 Analysis based on RMSE

Generally, a greater accuracy measure in terms of image fidelity is represented by smaller RMSE value. Table 4 shows the comparison of RMSE values generated by different fusion techniques using AFR.

Analysis of result shows that for different datastes, NSCT based image fusion technique using AFR exhibits the best results in terms of RMSE value, when compared to SWT and DWT based technique for the same fusion rule.

Amongst the fusion techniques, DWT technique exhibits low performance in terms of RMSE metric. This is due to the limited directionality and sub-sampling process associated with DWT technique, which causes introduction of false information. Thus, it can be inferred that NSCT based image fusion technique yields the highest measures in terms of colour radiometry, smoothness and preservation of edge information, when compared to other based image fusion techniques in terms of different scenarios. In other words, NSCT image fusion technique using AFR emerged as one of the efficient technique for feature identification.

4.2.2 Analysis based on PSNR

Table 4 shows the comparison of PSNR values generated by different fusion techniques using AFR. Irrespective of the datasets, it is found that NSCT based fusion using AFR technique produces good quality fused image, as indicated by high PSNR values, when compared to SWT and DWT based fusion technique under different scenario. Further, the fused image generated by DWT technique yields low values of PSNR. This may be due to the sub-sampling process involved in DWT, along with limited directional selectivity, which in turn incorporates false information in the fused image.

Thus, it is observed that NSCT technique using AFR is best in preserving the spectral and structural similarity information, which in turn offers good platform for feature identification. This is closely followed by SWT technique.

4.2.3 Analysis based on CC

The CC of two images is frequently used to specify their degree of correlation between the original image and the fused image. For a good correlation between the images, the value of CC must approaches one The results of CC for different fusion techniques using using AFR is tabulated in Table 4.

Irrespective of the datatsets, Table 4 shows that the NSCT based fusion technique create fused image with a high value of CC, which results in good spectral information in the fused image. This is followed by SWT and DWT techniques for the same scenario. Further, the low values for CC is observed for DWT technique. This is due to the fact that DWT being shift-variant technique produces artifacts in the resulting fused image.

Thus, it can be ascertained that the performance of NSCT technique using AFR is best amongst all the image fusion techniques, as explained by CC values. Further, the NSCT fusion technique under different scenario shows better results in terms of feature identification, when compared to the other techniques.

4.2.4 Analysis based on UIQI

Ideally, the value of UIQI should be equal to 1. It also considers the correlations between the fused and reference images.

The UIQI values obtained for different datasets shows that NSCT fusion technique using AFR is the best technique in terms of perpetuation of spectral and structural similarity quality, Among all the techniques, NSCT is the best technique, as indicated by UIQI values (Table 4). This is followed by SWT and DWT for the same fusion rule.

As seen from Table 4, DWT technique using AFR exhibit low quality fused image, amongst all the techniques. The is due to the sub-sampling process and limited directionality involved in DWT, which causes deformation in the resulting fused image.

5 *Conclusion*

In this study, a comparative assessment of different spatial-scale based fusion techniques in terms of different scenario. The experimental results show that the property of shift-invariance and multi-directionality of NSCT based fusion technique provides the best result, both in terms of datasets, qualitative and quantitative parameters. Further, quantitatively analysis shows that NSCT fusion technique provides better pan-sharpening results in terms of well-known global indexes, and is best for feature identification, when compared to the SWT and DWT techniques.

Finally, it can be concluded from this study is that feature identification can be analyzed effectively by using NSCT based fusion technique, in comparison to other fusion techniques.

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