Multi Imaging Sensor Data Fusion using 2D-DST

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ABSTRACT
Image fusion is a process of combining two or more images into a single image without any loss of information. Now-a-days, image fusion is playing a major role in current research areas. In this paper, a new data fusion algorithm is presenting called discrete sine transform based multi imaging sensor data fusion algorithm. Here multi imaging sensor data fusion using 2D-DST is developed, implemented and tested using image fusion quality evaluation metrics. The proposed fusion algorithms were compared with discrete Cosine transform based fusion algorithms and it is observed from the results that they are almost similar and comparable. The proposed fusion algorithms are computationally simple and could be used in real time applications.

Keywords
Discrete Sine Transform, Image Fusion, Discrete Cosine Transform.

1. INTRODUCTION
Of-late, many researchers developed different image fusion algorithms to combine multiple images into a single image. Image fusion using corresponding pixel averaging is the simplest method of all those different fusion algorithms [1]. In image fusion literature, no researchers use the simple and well-proven discrete Sine transform (DST) for fusion application. In this paper, an attempt has been made to use DST for developing image fusion algorithms. This paper introduced different DST based image fusion techniques and studied their performance. The goal of this paper is to check the performance of image fusion based on DST algorithm using different block sizes and to compare with DCT based image fusion algorithm [2, 3, 4].

2. DISCRETE SINETRANSFORM (DST)
By using real-matrix Discrete Sine Transform is similar to Discrete Fourier Transform (DFT) and it is twice the to the length of DFT. DST performed with odd symmetry on real data, the real function of a DFT is imaginary and odd function of a DFT is odd. In terms of sine functions oscillating at different frequencies DST produces discrete sequence. Eight types of DST variants are present, of which four are common and widely used for signal processing. Type-I DST variant is simple to use and it has its own inverse. Type-II and Type-III invariants are inverse to each other that is inverse of DST-II is DST-III and similarly inverse of DST-III is DST-II. In this paper, fusion algorithm was developed using DST-I. DST is a linear and invertible function.

The one dimensional (1D) Discrete Sine Transform $X(k)$ of a signal $x(n)$ of length N is defined as:

$$X(k)=\sqrt{\frac{2}{N}}\sum_{n=0}^{N-1}x(n)\sin\left(\frac{\pi(n+1)(k+1)}{N+1}\right),_{0\le k\le N-1}^{0\le n\le N-1} \quad (1)$$

DST-1 equation is orthogonal and it is exactly equivalent to a DFT of real sequence and at the 0^{th} and middle points scaled by 0.5 it is odd. DST-I variant has its own inverse.

The two-dimensional (2D) discrete sine transform $X(k_1,k_2)$ of an image $x(n_1,n_2)$ of size $N_1\times N_2$ is defined as:

$$X(k_1,k_2)=\sqrt{\frac{2}{N_1}}\sqrt{\frac{2}{N_2}}\sum_{n_1=0}^{N_1-1}\sum_{n_2=0}^{N_2-1}x(n_1,n_2)\sin\left(\frac{\pi(n_1+1)(k_1+1)}{N_1}\right)\sin\left(\frac{\pi(n_2+1)(k_2+1)}{N_2}\right) \quad (2)$$

Where, $0\le k_1,k_2\le N_1-1,N_2-1$

Here, 2D DST is a self inverse [5, 6].

3. IMAGE FUSION
The architecture of 2D DST based image fusion is shown in Figure 1. The images to be fused are divided into non-overlapping blocks of size $N\times N$. DST is performed on corresponding blocks of images to be fused and fusion rules are applied on DST coefficients to get the fused DST coefficients. The process repeats for each block of an image. This gives the fused image as output.

The details of fusion rules are presented in this section [5].Let us consider X_1 be the DST coefficients of image block from image 1 and similarly X_2 be the DST coefficients of image block from image 2. Surmise that the image block is of size $N\times N$ and X_f be the fused DST coefficients.

3.1 DSTav
In this Fusion rule, all the DST coefficients from both image blocks are averaged to get fused DST coefficients. DSTav is a basic image fusion technique in DST domain and it is simple technique.

$$X_f(k_1,k_2)=0.5*(X_1(k_1,k_2)+X_2(k_1,k_2)) \quad (3)$$

Where, $k_1,k_2=0,1,2,.......,N-1$

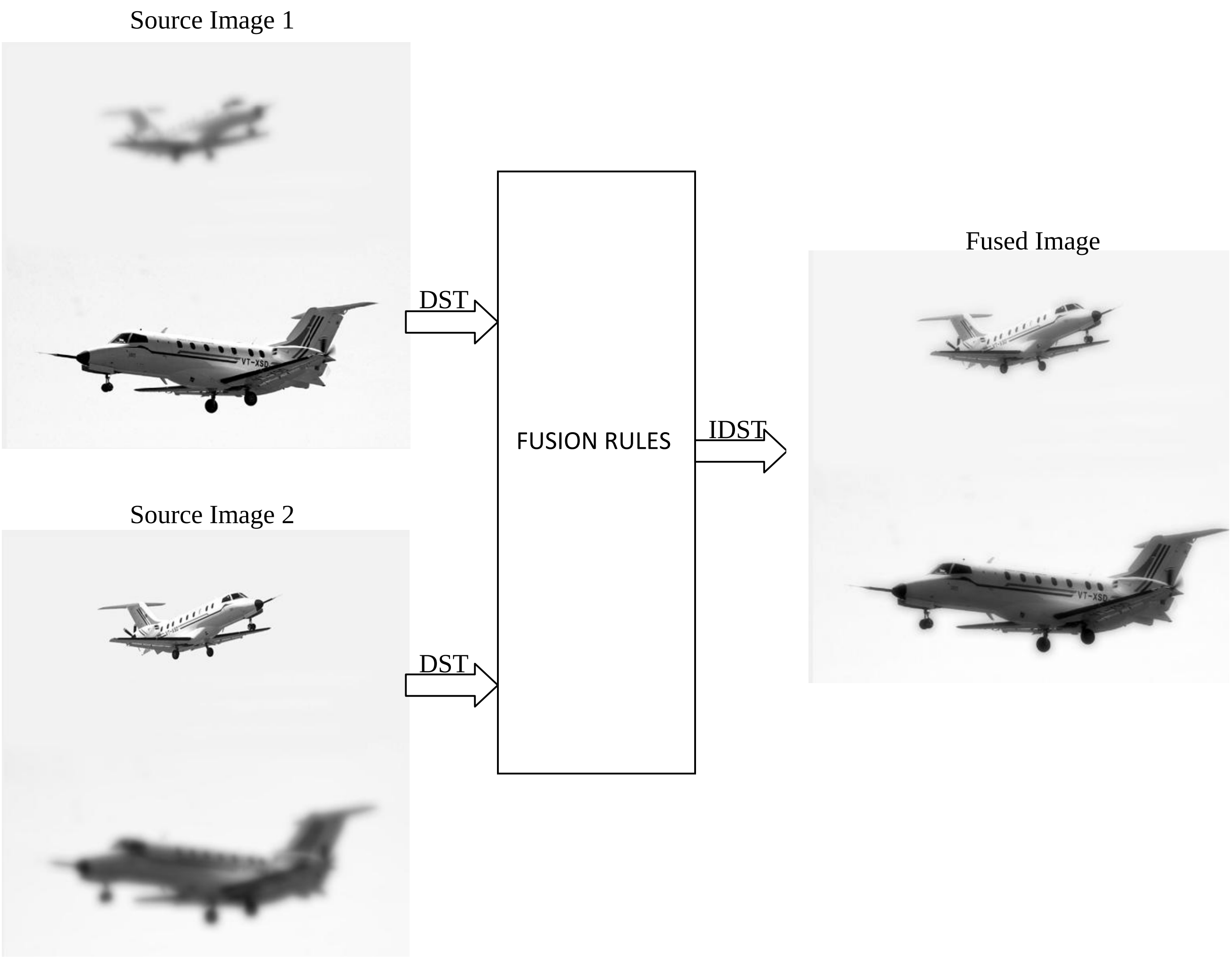

Figure 1. Framework of 2D-DST based image fusion architecture

3.2 DSTmax

In this method, DC components from both the images to be fused are averaged as shown in eq.(4). Corresponding maximum magnitude AC coefficients,from the images to be fused, are considered from the eq. (5) whichmake sharper brightness changes in the images such as edges, object boundaries etc. Both DC and AC coefficients oscillates around zero.

$$X_f(0,0) = 0.5(X_1(0,0) + X_2(0,0)) \qquad (4)$$

$$X_f(k_1,k_2) = \begin{cases} X_1(k_1,k_2), & |X_1(k_1,k_2)| \geq |X_2(k_1,k_2)| \\ X_2(k_1,k_2), & |X_1(k_1,k_2)| < |X_2(k_1,k_2)| \end{cases} \qquad (5)$$

3.3 DSTah

By collecting the lowest AC components and including DC coefficients averaging process can be performed and the AC coefficients which are remained, are chosen based on largest magnitude.

$$X_f(k_1,k_2) = 0.5*(X_1(k_1,k_2) + X_2(k_1,k_2)) \qquad (6)$$

Where $k_1, k_2 = 0,1,2,.......,0.5N$

$$X_f(k_1,k_2) = \begin{cases} X_1(k_1,k_2), & |X_1(k_1,k_2)| \geq |X_2(k_1,k_2)| \\ X_2(k_1,k_2), & |X_1(k_1,k_2)| < |X_2(k_1,k_2)| \end{cases} \qquad (7)$$

Where, $k_1, k_2 = 0.5N, 0.5N+1, 0.5N+2, ...N-1$

3.4 DSTe

In DSTe DC components are averaged together, and the AC coefficients consider the largest energy frequency bands.

$$X_f(0,0) = 0.5*(X_1(0,0) + X_2(0,0)) \qquad (8)$$

$$X_f(k_1,k_2) = \begin{cases} X_1(k_1,k_2), & E_{j1} \geq E_{j2} \\ X_2(k_1,k_2), & E_{j1} < E_{j2} \end{cases} \qquad (9)$$

Where, $j = k_1 + k_2$ and E_{j1} and E_{j2} are energies taken from the reference [3].

The fused image will get by applying the DST on fused coefficients as: $x_f = DST(X_f)$

***Note**: DCT based image fusion algorithms are very similar to DST based image fusion algorithms (Section 3.1 to 3.4) by simply replacing DST by DCT.*

4. FUSION EVALUATION METRICS

Image fusion process is used to get good quality image and to evaluate the fusion quality, many fusion quality evaluation metrics are proposed in the open literature. The fusion evaluation metrics when reference image is used are as follows [5, 6]:

4.1 Spatial Frequency (SF)

In spatial domain the frequency point out the entire activity level in the fused image and it is computed as row and column frequency of the images. Spatial frequency criterion is:

$$SF = \sqrt{RF^2 + CF^2} \tag{10}$$

Where, row frequency of the image:

$$RF = \sqrt{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}[x_f(m,n) - x_f(m,n-1)]^2} \tag{10a}$$

Column frequency of the image:

$$CF = \sqrt{\frac{1}{MN}\sum_{n=1}^{N}\sum_{m=2}^{M}[x_f(m,n) - x_f(m-1,n)]^2} \tag{10b}$$

SF indicates the overall activity level in the fused image. The fused image with high SF will be considered [5].

4.2 Peak Signal to Noise Ratio (PSNR)

Its value will be high when the reconstructed and reference images are similar. Higher PSNR value implies better reconstruction. The peak signal to noise ratio is computed as [7]:

$$PSNR = 10\log_{10}\left(\frac{L^2}{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\left(x_r(m,n) - x_f(m,n)\right)^2}\right) \tag{11}$$

Where, L is the number of gray levels in the image and x_r is the reference/ground truth image.

4.3 Entropy (H)

Entropy is used to measure entire particulars content of the image. The particulars content of a fused image using entropy is [8]:

$$H = -\sum_{i=0}^{L_H} h_{x_f}(i)\log_2 h_{x_f}(i) \tag{12}$$

Where, $h_{x_f}(i)$ is the fused image normalized histogram, x_f and L_H number of frequency bins in the histogram. Entropy is sensitive to noise and other unwanted rapid fluctuations. Hence, information entropy is used to measure the rich information of the image. Therefore, higher entropy means better performance.

5. RESULTS AND DISCUSSION

The images (source) to be fused along with reference image are taken from ref. [5] to demonstrate the proposed image fusion algorithms. The ground truth (reference) and source images are shown in Figure 2 and Figure 3 respectively. One can see from Figure 3a that one aircraft is in focus (bottom) and the other one is out of focus (top) and vice-versa in Figure 3b. Figure 3b shows the complementary information and hence fusion is required to get image with both aircrafts (bottom & top) with in focus.

Figure 2: Ground Truth Image-SARAS

Figure 3(a): Source Image1-SARAS

Figure 3(b): Source Image2-SARAS

Fused images using proposed algorithms and DCT based image fusion algorithms [5] are shown in Figures 4 to 7.From Figure 4, it can be observed that the fused images with DCTe and DSTe are almost similar but DSTe based fused image is little bit not clear. Similar observations are made from Figures 5 and 6. From Figure 7, it is observed that the fused images by DCTav and DSTav are appearing same and hence these algorithms provide best quality of fused images.

Figure 4(a):Fused image using DSTe fusion algorithm

Figure 4(b): Fused image using DCTe fusion algorithm

Figure 5(a): Fused image using DSTah fusion algorithm

Figure 5(b): Fused image using DCTah fusion algorithm

Figure 6(a): Fused image using DSTmax fusion algorithm

Figure 6(b): Fused image using DCTmax fusion algorithm

Figure 7(a): Fused image using DSTavfusion algorithm

Figure 7(b): Fused image using DCTavfusion algorithm

The computational time of the proposed fusion algorithms are shown in Table 1. It is observed that, in DST based fusion process at 16x16 block size it is taking less time for all fusion rules except for DSTe(at 32x32 it is taking less time). whereas, in DCT at 128x128 block size it is taking less time for all fusion rules except for DSTe(at 64x64 it is taking less time).

Table 1. Computational Time (in sec)

Fusion rules	Block Size(rows & columns)								
	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256	512x512
DSTav	7.4232	3.8034	1.9731	**1.8318**	2.6496	4.7131	9.1133	17.9871	35.9240
DCTav	22.6578	5.9152	1.5946	0.4896	0.1859	0.1617	**0.1085**	0.2009	0.2738
DSTmax	7.8969	3.4496	2.0177	**1.8393**	2.6509	4.7310	9.0845	18.1372	36.0051
DCTmax	23.1537	6.0213	1.6209	0.4881	0.1886	0.1691	**0.1164**	0.2028	0.2831
DSTah	8.7456	3.6002	2.0647	**1.8703**	2.6434	4.8103	9.0807	17.9239	35.8718
DCTah	23.7942	6.1585	1.6665	0.5042	0.1988	0.1665	**0.1226**	0.2065	0.2847
DSTe	27.0125	14.0739	7.4312	5.4210	**5.3831**	8.2326	14.9772	29.0308	58.1472
DCTe	34.4017	11.9302	4.8228	2.3368	1.4845	**1.4178**	1.8222	4.2950	9.7422

Quality evaluation metrics for fused image using 2D-DST based image fusion algorithms are given in Table 2&3. The metrics shown with bold indicates better results and corresponding algorithms will be the best among others. It is observed that SF is same in average based fusion algorithm irrespective of block size in both DST and DCT fusion techniques. The compared evaluation metrics of DST and DCT based image fusion using 8x8 block is shown in Table-4.It is observed that, fusion algorithm based on DST and DCT are performing almost similar. In fact, DSTav provides better PSNR than DCTav as shown in Table 4. It is also observed that, DST av shows better fusion image compare to other DST based fusion algorithms followed by DSTe. These results are comparable with DCT based fusion algorithms.

Table 2. Spatial Frequency

Fusion rules	Block Size(rows & columns)								
	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256	512x512
DSTav	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358
DCTav	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358	0.0358
DSTmax	0.0450	0.0489	0.0515	00531	0.0535	0.0546	0.0555	0.0548	**0.0569**
DCTmax	0.0544	0.0643	0.0667	**0.0669**	0.0668	0.0668	0.0666	0.0667	0.0611
DSTah	**0.0557**	0.0503	0.0497	0.0486	0.0474	0.0487	0.0493	0.0474	0.0508
DCTah	**0.0544**	0.0528	0.0510	0.0501	0.0496	0.0493	0.0491	0.0489	0.0463
DSTe	0.0556	0.0560	0.0580	0.0610	0.0631	**0.0677**	0.0676	0.0668	0.0644
DCTe	0.0544	0.0642	0.0666	**0.0668**	**0.0668**	0.0667	0.0667	0.0667	0.0520

Table 3. Entropy

Fusion rules	Block Size(rows & columns)								
	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256	512x512
DSTav	**4.0546**	4.0232	4.0217	4.0152	4.0181	4.0182	4.0174	4.0182	4.0176
DCTav	3.9888	3.9888	3.9891	3.9889	3.9882	3.9937	3.9933	**3.9978**	3.9943
DSTmax	3.9478	3.9000	3.9165	3.9698	4.0570	4.1263	4.2360	4.5376	**4.6268**
DCTmax	4.0179	4.0090	4.0099	4.0006	3.9488	3.9918	4.1587	3.7418	**5.5020**
DSTah	3.9478	3.9480	3.9783	4.0183	4.0775	4.1074	4.2049	4.3844	**4.4422**
DCTah	4.0179	4.0246	4.0253	4.0286	4.0412	4.0701	4.1477	4.1916	**4.8325**
DSTe	3.9464	3.8561	3.8397	3.8748	3.9539	4.0498	4.0651	4.0914	**4.3567**
DCTe	4.0173	4.0064	4.0057	3.9889	3.9385	3.9669	3.9820	3.7125	**4.8561**

Table 4. Comparison between DST and DCT

	Block Size(8x8)							
	DSTav	DSTmax	DSTah	DSTe	DCTav	DCTmax	DCTah	DCTe
Computational Time(in sec)	1.9731	2.0177	2.0647	7.4312	**1.5946**	1.6209	1.6665	4.8228
Spatial Frequency	0.0358	0.0515	0.0497	0.0580	0.0358	**0.0667**	0.0510	0.0666
PSNR	**46.7141**	43.9522	45.0890	44.4066	38.4255	40.7588	38.6715	40.7857
Entropy	4.0217	3.9165	3.9783	3.8397	3.9891	4.0099	**4.0253**	4.0057

6. CONCLUSIONS

Multi imaging sensor data fusion algorithms using 2D-DST are presented and evaluated using fusion quality evaluation metrics. The results are compared with DCT based fusion algorithms available in open literature [5]. From this study, it is concluded that fusion algorithms based DST and DCT are performing almost similar. The future scope of the proposed work is to apply these algorithms for real-time image fusion applications.

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