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Real Time Image Fusion using Multi Resolution Discrete Sine Transform

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ABSTRACT

Image fusion is a process, used to fuse two or more images into one image without any loss of data, images are taken from different sensors in different Field Of View (FOV). In recent days, image fusion is playing an important role in research areas. In open literature different fusion techniques are available like Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT) etc., this paper is aimed at the design and development of image fusion using MDST for still images and for real-time images. Multi-resolution DST (MDST) has been developed for multi imaging sensor data fusion. This fusion algorithm has been evaluated using both still images as well as real-time images. IR and EO cameras were connected to multi-functional display system through frame grabber. MDST algorithm has been ported (Visual C++) and tested on10.4” multi function display. The MDST results are comparable with DWT (Discrete Wavelet Transform). The proposed fusion algorithm can be used in battlefields, remote sensing applications and medical imaging etc.

Keywords: *DST, Image processing, Multi resolution, Real-Time Image fusion, Performance evaluation metrics.*

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I. INTRODUCTION

In low visibility conditions like foggy weather or during nights, there are possibilities in which pilot can lose situational awareness. In such conditions, an enhanced view of the surroundings is needed. Therefore, in this paper a technique of Multi-Imaging Sensor Data Fusion using MDST is implemented and evaluated. It is the fusion of EO and IR images and the fused image is better visualized in low-visibility conditions. In many situations image processing require high spatial and spectral data of an image, due to limited focus of optical lens it is not possible to get total data of an image (with all objects focused). To avoid this multi-focus image fusion process is used [1]. Mostly the Real-world objects not contain structures in different scales or resolutions, multi-scale methodologies can give a way to overcome this kind of problems and as a result, multi-resolution image processing systems are widely utilized as a part of the advancement of image fusion strategies. When the images are in the same scene but have different field of view image registration is required, then fusion process can be done [2]. In this paper, a visual image and a thermal image are considered for fusion. While fusing EO image (color image of RGB format) and IR image (a gray image), the fusion has to be taken place at intensity level, as this preserves the color information of EO image. Therefore, the EO image is to be converted from RGB to HSI (Hue Saturation Intensity) before performing the fusion [3]. After the fusion of Intensity component (I) of EO image and IR image, an H and S components of EO image have to be added to the fused image and is to be converted to RGB to get back the color information. Real-Time image fusion is performed on Electro-optical (EO) and Infrared (IR) images obtained from Enhanced Vision System (EVS).

II. DISCRETE SINE TRANSFORM

By using real-matrix, Discrete Sine Transform is similar to Discrete Fourier Transform (DFT) and it is twice 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. DST produces discrete sequence when sine functions oscillate at various frequencies. 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 [4].

2.1 DST-I

One dimensional discrete sine transform can be represented as:

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

The DST-I is orthogonal and it is exactly equivalent to a DFT of real sequence that is odd around the 0th and middle points, scaled by 0.5. The

DST-I is its own inverse [4]. The 2D (two dimensional) discrete sine transform $X(k_1,k_2)$ of an image $x(n_1,n_2)$ of size $N_1 \mathrm{x} N_2$ defined as in equation (2):

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

Where, $0 \le n_1, n_2 \le N_1 - 1, N_2 - 1$

One can see that there is no DC component in this transform unlike FFT and DCT. Both DST and IDST are separable transformations and the upside of this property is that 2D DST can be obtained in two stages by progressive 1D DST operations on columns followed by the resulting rows (or vice versa) of an image $x(n_1,n_2)$ as shown in equation (3):

$$X(k_1,k_2) = \sqrt{\frac{2}{N_2}} \sum_{n_2=0}^{N_2-1} \left[\sqrt{\frac{2}{N_1}} \sum_{n_1=0}^{N_1-1} x(n_1,n_2) \sin\left(\frac{\pi(n_1-1)(k_1-1)}{N_1}\right) \right] \sin\left(\frac{\pi(n_2-1)(k_2-1)}{N_2}\right) \quad (3)$$

III. MDST (MULTI RESOLUTION DISCRETE SINE TRANSFORM)

3.1 Multi resolution analysis

Multi-resolution image analysis utilizing discrete sine transform (MDST) is particularly like wavelet transform. Here the image is divided into low pass and high pass finite impulse response channel. Then to get the first decomposition level output of each channel is decimated by a component of two [5, 6].

3.2 Multi resolution image decomposition

MDST decomposition levels are shown in Fig 1. The image which to be decomposed is changed into frequency domain by applying DST in column wise. Low passed image 'L' can get by taking IDST on first 50% of focuses (1to $0.5N$). Therefore, high passed image 'H' can get by taking IDST on second 50% of focuses ($0.5N$ to N) points. By applying the DST in row wise, the low passed image 'L' is transformed into frequency domain. Apply IDST on first 50% of focuses to get low passed image 'LL' and comparably apply IDST on the remaining half to get the low-high passed image 'LH'. The high passed image 'H' is changed into frequency domain by applying DST row wise. Take IDST on initial half of focuses (in row wise) to get high-low passed image 'HL' and likewise take IDST on staying half to get the high passed image 'HH'. The low passed image 'LL' contains the normal image data relating to low frequency band of multi scale decomposition. The low passed image 'LL' can be considered as smoothed and sub tested form of the source image. Low passed image indicate the approximation of original image, and 'LL', 'LH', 'HL', and 'HH' are sub images which contain directional (horizontal, vertical and diagonal) data of the source image because of spatial introduction. The reconstruction of an image can be done by applying the above process to low pass coefficients (LL). Pixel level image fusion based on MDST can be observed in reference [5, 6]. The source images are decomposed into different levels using MDST. The decomposed images from I_1 and I_2 can be stated as in equation (4):

$$I_1 \rightarrow \left\{ {}^1LL_D, \left\{ {}^1LH_d, {}^1HH_d, {}^1HL_d \right\}_{d=1,2,\ldots,D} \right\}$$
$$I_2 \rightarrow \left\{ {}^2LL_D, \left\{ {}^2LH_d, {}^2HH_d, {}^2HL_d \right\}_{d=1,2,\ldots,D} \right\} \quad (4)$$

At every decomposition level $d \ (d = 1,2,\ldots,D)$, the combination will choose total estimation of the two detailed MDST coefficients, since the detailed coefficients compares with brightness changes in the images, for example, edges and object boundaries and so on. These coefficients fluctuate around zero. At the coarsest level $(d = D)$, the combination, take normal MDST estimated coefficients. Since, the approximation coefficients at coarsest level are smoothened and sub-sampled version of the original image. The fused image I_f can be computed using equation (5):

$$I_f \leftarrow \left\{ {}^fLL_D, \left\{ {}^fLH_d, {}^fHH_d, {}^fHL_d \right\}_{d=1,2,\ldots,D} \right\} \quad (5)$$

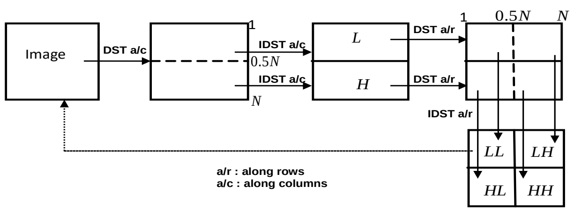


Fig 1 Multi resolution decomposition structures

IV. MULTI-IMAGING SENSOR DATA FUSION

Image fusion using MDST is performed and evaluated for still images and real-time images.

4.1 Fusion for still images
Fig. 2 describes the steps involved in fusion of still images.

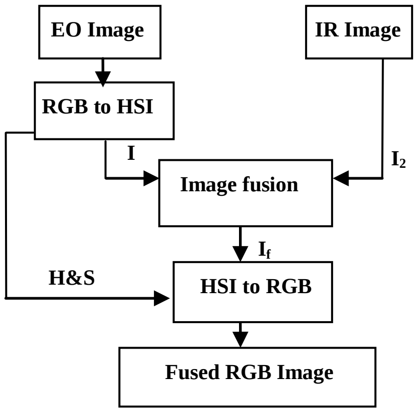


Fig 2 Steps involved in image fusion of still images

While fusing EO image (color image of RGB format) and IR image (a gray image), the fusion has to be taken place at intensity level, as this preserves the color information of EO image. Therefore, the EO image is to be converted from RGB to HSI (Hue Saturation Intensity) before performing the fusion. After the fusion of Intensity component (I) of EO image and IR image, an H and S components of EO image have to be added to the fused image and is to be converted to RGB to get back the color information.

4.2 Real-time image fusion
Fig. 3 describes the steps involved in fusion of real-time images.

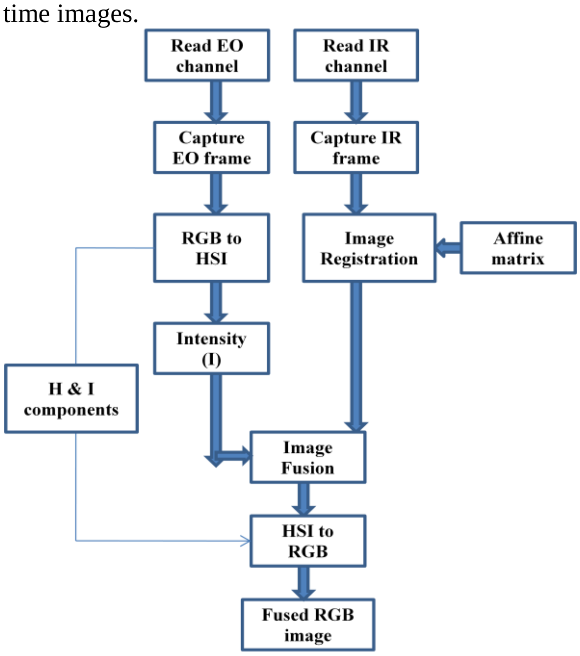


Fig 3 Steps involved in image fusion of real-time images

In this affine matrix is produced by performing image registration in MATLAB and that matrix is used while performing real-time image fusion in Visual C++.

4.3 Hardware setup

Both the cameras can be turned on by using battery. The outputs of the cameras are connected to the 10.4" Multi-Function Display through two RS-170 ports respectively in which frame grabber is inserted. The 10.4" Multi-Function Display is turned on by using +12 V power supply. The hardware setup used for developing the image fusion techniques is shown in the Fig. 4.

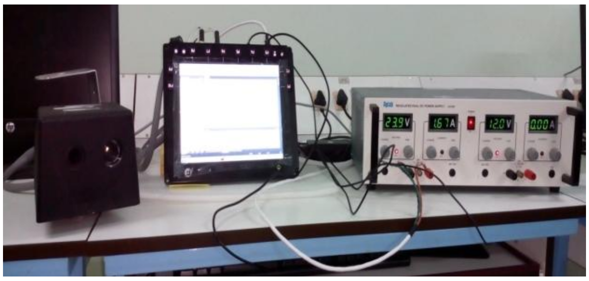


Fig 4 Hardware setup

The LWIR incorporates an uncooled 324x256 pixels micro bolometer. It has an internal heater to defrost its protective window. Hardware specifications of LWIR and EO cameras can be referred from reference [7].

4.1.1 System Requirements
To run this application some specifications are necessary, those are mentioned in Table 1.

TABLE 1: System specifications

S. No	**Specification**	**Requirement**
1	Processor	3.4 GHz processor or more
2	RAM	4GB or more
3	Hard Disk space	10GB or more
4	USB port	2.0 or higher version should be there
5	Frame Grabber driver	Direct show windows driver version 1.1.10 should be installed
6	Visual Studio	2008 or latest should be installed

V. PERFORMANCE 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 [8, 9]:

5.1 Entropy(H)

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

$$H = -\sum_{i=0}^{L_H} h_{x_f}(i) \log_2 h_{x_f}(i) \quad (6)$$

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.

5.2 Standard Deviation (SD)

Standard deviation measures data value set quantity. Low standard deviation indicates the data values tend to be close to the mean of the set and high standard deviation value indicates that the data points spread out over a wide range of values. In image processing standard deviation is variation of pixel values with respect to the mean of all pixel values of an image.

$$\sigma = \sqrt{\frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (I_f(x,y) - \mu)^2} \quad (7)$$

Here μ is the mean of all pixel values in the image I_f.

5.3 Peak Signal to Noise Ratio (PSNR)

PSNR value will be high when the reconstructed and source images are similar. Higher PSNR value indicates better reconstruction. The peak signal to noise ratio is given in equation (8):

$$PSNR = 10 \log_{10} \left(\frac{L^2}{\frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} \left(x_r(m,n) - x_f(m,n) \right)^2} \right) \quad (8)$$

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

5.4 Energy

Energy returns the sum of squared elements in the Gray Level Co-occurrence Matrix (GLCM). It is also known as uniformity, uniformity of energy or angular second moment. The energy lies between 0&1.

$$E = \sum_{i=1}^{8} \sum_{j=1}^{8} g(i,j)^2 \quad (9)$$

5.5 Homogeneity

Homogeneity is a condition in which all the constituents are of the same nature. In image processing, it returns a value that measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal i.e. if all the pixels in a block are within a specific dynamic range. The range homogeneity is from zero to one. Homogeneity is 1 for a diagonal GLCM.

$$I_{\text{hom}} = \sum_{i=1}^{8} \sum_{j=1}^{8} \frac{g(i,j)}{1 + |i-j|} \quad (10)$$

VI. RESULTS AND DISCUSSION

The fusion method using Multi Resolution Discrete Sine Transform is implemented by using Open Source Computer Vision (OpenCV) image processing library in Visual Studio Platform as Win32 console application and the programming language used to implement the method is C++. This application is capable to capture real time video data from two cameras and simultaneously fuse both the camera output as a single video data. In this application, offline image registration is done for two sample images of EO and IR cameras respectively by using Control Point image registration toolbox of MATLAB. Then that transformation matrix (Affine Transform) is taken to the OpenCV project and used for the real time image fusion. In control point image registration technique, the user has to take same feature points on both images manually as shown in Fig. 5.

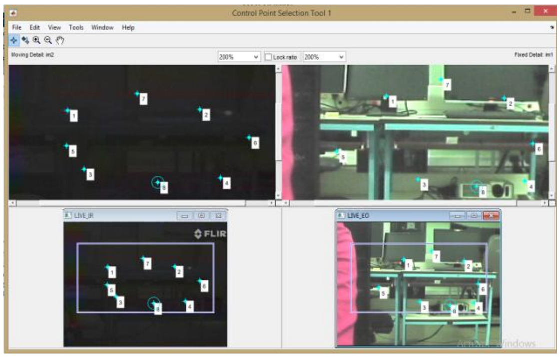


Fig 5 Control Point selection toolbox

The Affine matrix for the given scenario is shown in Fig 5 is given below:

Affine matrix= $\begin{bmatrix} 1.1300 & -0.0287 & -10.3342 \\ -0.0489 & 0.9721 & 6.0981 \end{bmatrix}$

Then the geometric transformation (fitgeotrans) has to be applied on the feature points, which give

transformation matrix (Affine matrix) that can be used for real time image registration.
The RGB to HSI and HIS to RGB conversions are validated by comparing original and reconstructed image as shown in Fig 6.

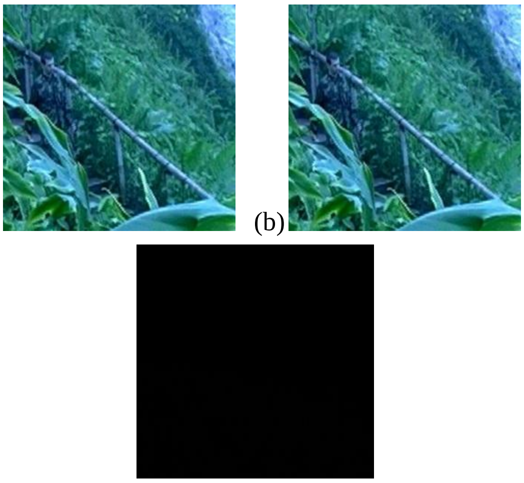

(a) (b) (c)

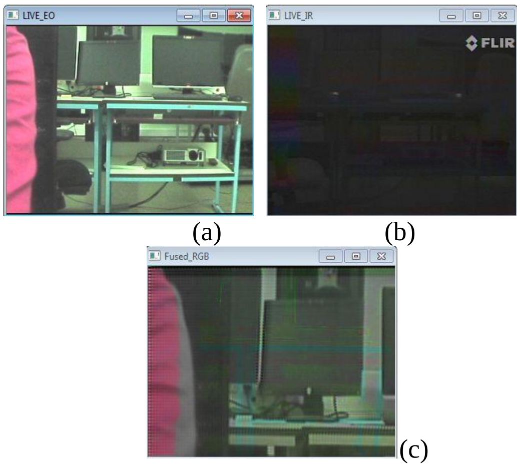
Fig 6 Validation of RGB to HSI conversion (a) Original RGB Image, (b) Reconstructed RGB Image, (c) Error image

At First consider still EO and IR images which are shown in Fig. 7 (a) and 7 (b). By applying image fusion techniques for still images the resultant Fused Image is shown in Fig 7 (c).

(a) (b) (c)

Fig 7 Image Fusion for Still Images (a) EO image, (b) IR image, (c) Fused Image

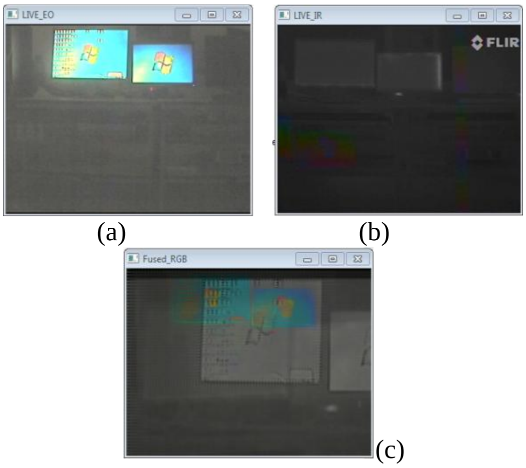
After the successful implementation of fusion techniques for the still images, which are implemented for the real time camera images and performance of the fusion techniques for the real time images is evaluated with fusion performance metrics. The EO and IR images captured from EVS camera are shown in Fig 8(a) & (b). During day time, the MDST technique is given high weightage to the horizontal, vertical and diagonal information's of the EO image as shown in Fig 8(c). So the fused image contains most of the information from EO and temperature highlighted information from IR.



(a) (b) (c)

Fig 8 Image Fusion for Real-Time Images (a) EO (b) IR (c) Fused Image in day effect

The EVS camera captured images in night light are shown in Fig 9(a) & (b). During night time, it is given high weightage to the horizontal, vertical and diagonal information's of IR edges as shown in Fig 9 (c). So the fused image contains most of the information from IR and color sensitive information from EO.



(a) (b) (c)

Fig 9 (a) EO (b) IR (c) Fused Image in night effect

The performance evaluation metrics which are compared with well known Discrete Wavelet Transform are given in Table 2. From the comparison it can be observed that MDST gives high standard deviation, signal to noise ratio and energy as compared to DWT. The metrics shown with bold indicates better results and corresponding algorithms will be the best among others. From the results it can be observed that Multi-Resolution Discrete Sine Transform gives almost similar results as compared to the well known Discrete Wavelet Transforms.

TABLE 2: Performance evaluation metrics

Metrics	Still Images		Real-Time Images	
	MDST	DWT	MDST	DWT
Entropy	5.9010	**6.4293**	6.1323	**6.6528**
PSNR	**4.5672**	3.4473	**4.3020**	2.9799
Standard Deviation	**33.8817**	27.2323	**54.544**	30.3358
Energy	**0.3232**	0.1397	0.2203	0.2719
Homogeneity	0.9163	**0.9205**	0.9437	**0.9690**

VII. CONCLUSION

An algorithm for multi-resolution image fusion using discrete Sine transform (MDST) has been presented and evaluated. The efficiency of MDST and IMDST for multi-resolution image processing has been tested. From the performance evaluation metrics, it is observed that there is no information loss by applying MDST on images. The performance of the proposed fusion algorithm has been compared with well-known wavelets based image fusion technique and it can be observed that MDST based image fusion gives almost similar results as Discrete Wavelet Transform.

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