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Real-Time Implementation of Multi-Imaging Sensor Data Fusion Techniques

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ABSTRACT
Enhanced Vision System (EVS) is one of the most advanced technologies that provide good situational awareness to the pilot, which is essential to fly safely under poor visibility conditions. EVS uses Electro-Optical (EO) and Infra-Red (IR) imaging sensors. Individual images obtained from these sensors provide different information of the terrain and surroundings, but when they are fused, it gives better information which improves the visual perception. Fusion of images obtained from such multi-sensors can be achieved using different techniques. For fusing the EO and IR images of EVS, four fusion methods viz., Alpha Blending, Principal Component Analysis (PCA), Laplacian Pyramid, and Discrete Wavelet Transform (DWT) have been implemented and tested. Laplacian pyramid based image fusion technique proved to provide better fusion when compared to the other techniques.

General Terms
Electro-Optical; Infra-Red; multi-sensors

Keywords
Image fusion; image processing; Laplacian Pyramid; wavelets

1. INTRODUCTION
Image Fusion is a process of combining the features of two or more images of a scene into a single composite image. It results in an image which is more informative and is suitable for visual perception or computer processing. In Image Processing, there are many image fusion methods which are capable to do this [1]. When the images that are to be fused are in the same scene but have different Field of View (FOV), Image Registration is required. While fusing EO (RGB) and IR (Gray level) images, the fusion has to be taken place at the intensity level for retaining the color information of EO image. Therefore, the EO image has to be converted into HSI (Hue Saturation Intensity) image prior to fusion. After the fusion of Intensity component (I) of EO image and IR image, H and S components of EO image have to be added with the fused image to get back the color information.

1.1 Image Registration
Image Registration is a process of aligning two or more images of the same scene. In this application, off-line image registration (both EO and IR imaging sensors are in the same platform and there is no relative movement between these sensors and hence online registration is not required) is done for two sample images of EO and IR cameras respectively by using Control Point Image Registration tool box of MATLAB. The transformation matrix (Affine Transform) obtained from MATLAB is used in the OpenCV project for the real time image fusion. In control point image registration, the user has to select same feature points on both images manually, as shown in Figure 1.

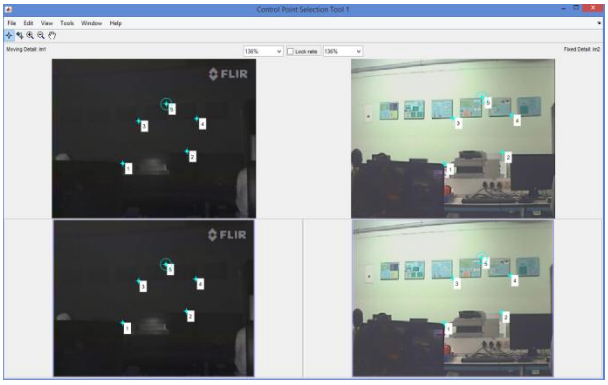


Figure 1: Control Point Image Registration

The Affine matrix for the given scenario in Figure 1, is as follows,

$$\text{Affine Matrix}=\begin{bmatrix} 0.9718 & 0.0340 & 30.2677 \\ 0.0653 & 1.1225 & -22.0034 \end{bmatrix}$$

Then, geometric transformation (MATLAB function fitgeotrans) has to be applied on the feature points, which gives transformation matrix (Affine matrix) that can be used for real time image registration.

1.2 RGB to HSI Conversion
RGB and HSI are color models of an image. In RGB model, colors are encoded by the amount of red light, green light, and blue light emitted and they are represented numerically with a set of three numbers, each of which ranges from 0 to 255. White has the highest RGB value of (255, 255, 255) and black has the lowest value of (0, 0, 0). HSI color model encodes colors according to their Hue, Saturation, and Intensity. Here, hue of a color is its angle measure on a color wheel. Pure red hues are 0°, pure green hues are 120°, and pure blues are 240°. Intensity is the overall lightness or brightness of the color, defined numerically as the average of the equivalent RGB values [2]. The equations for the conversion of RGB values to HSI values are as follows,

$I = (R+G+B)/3$, I is Intensity value (1)

if $(R+G+B)=0$

$S = 1-3*(Min/\varepsilon)$, ε (2.2204*10-16) is epsilon (2)

else

$S = 1-3*(Min / (R+G+B))$ (3)

if $B<=G$

H = cos-1[(R–0.5G–0.5B)/√ (R² + G² + B² – RG – RB – G)] (4)

else

H = (360° /180) – cos-1[(R – 0.5G – 0.5B)/√ (R² + G² + B² – RG – RB – GB)] (5)

Where, the inverse cosine output is in radians.

1.3 HSI to RGB Conversion

The R, G, and B are given by,

If 0 < H < (120° /180)

R= I(1+S cos(H)/cos((120° /180) – H)) (6)
G=3I – (R+B) (7)
B= I(1– S) (8)

If (120° /180) < H < (240° /180)

R=I(1– S) (9)
G=I(1+Scos(H – (120°/180))/cos(–H)) (10)
B=3I – (R+G) (11)

If (240° /180) < H < (360° /180)

R=3I – (B+G) (12)
G=I (1–S) (13)

B=I(1+Scos(H–(240°/180))/cos((300°/180)–H))(14)

RGB to HSI and HIS to RGB conversions are validated by comparing original and reconstructed as shown in Figure 2.

Figure 2: Validation of RGB to HSI conversion (a) Original RGB Image, (b) Reconstructed RGB Image, (c) Error Image

2. IMAGE FUSION TECHNIQUES

The steps involved in real-time image fusion of EO and IR camera images are shown in Figure 3.

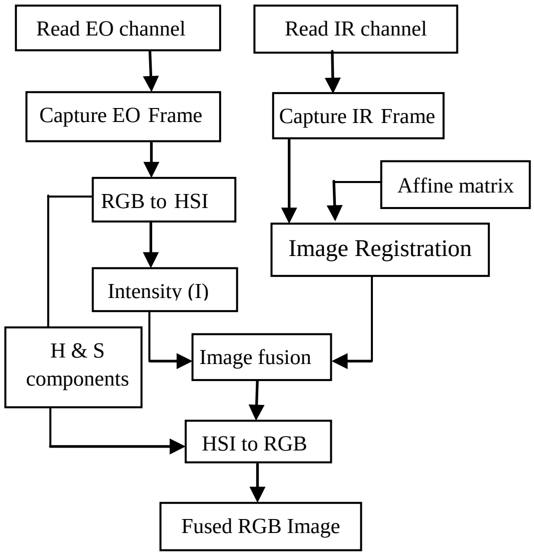


Figure 3: Steps involved in real-time image fusion

2.1 Alpha Blending

Alpha blending is a process of combining an image with the background and the transparency of background and foreground images is controlled by Alpha value and (1-Alpha value) respectively.

$$I_f(x,y) = Alpha * I_1(x,y) + (1 - Alpha) * I_2(x,y) \quad (15)$$

Where, $0 \le Alpha \le 1$

I_f - fused image,

I_1 and I_2 - input images to be fused

(x, y) - Pixel index

In EVS, the EO image is taken as background image because it has higher field of view. The transparency of background image is decided by the $Alpha$ value provided by the user. The alpha value is limited from 0 to 1. So, the transparency of foreground image is equal to $(1 - Alpha)$ value. Alpha blending can be done by using add weighted OpenCV function.

2.2 Principal Component Analysis

The information flow diagram of PCA-based image fusion algorithm is shown in Figure 4. The input images (images to be fused), $I_1(x, y)$ and $I_2(x, y)$ are arranged in two column vectors and their empirical means are subtracted. The resulting vector has a dimension of $N \times 2$, where N is length of each image vector. Eigen vector and Eigen values for the resulting vector are computed and the eigenvectors corresponding to the larger eigenvalue are obtained. The normalized components P_1 and P_2 (i.e., $P_1 + P_2 = 1$) are computed from the obtained eigenvector.

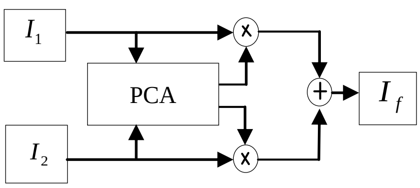


Figure 4: PCA based image fusion

The fused image is: $I_f(x,y) = P_1 I_1(x,y) + P_2 I_2(x,y)$ (16)

2.3 Laplacian Pyramid

Image pyramid is a multi-scale representation of an image in which, image is subjected to repeated smoothing and subsampling.

There are two types of image pyramids which are low pass and band pass. A low pass pyramid is constructed by smoothing the image with an appropriate filter and then subsampling it by a scaling factor of 2 repeatedly. The Gaussian pyramid is one of the examples for low pass pyramid.

$$I_{dk} = g * I_k \tag{17}$$

Here, g is the Gaussian convolution kernel, I_k is input image of the k[th] level of Gaussian pyramid and I_{dk} is the down sampled image of k[th] level, whereas band pass pyramid is constructed by forming the difference between the adjacent levels of image pyramid and performing some kind of image interpolation between adjacent levels of resolution. The Laplacian is computed as the difference between the original image and the low pass filtered image, so that the Laplacian pyramid is set of band pass filtered images.

$$I_{Lk} = I_K - I_{uk} \tag{18}$$

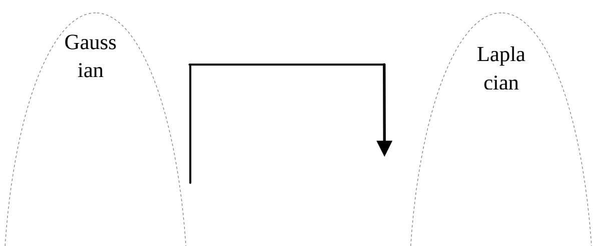
I_{Lk} is the Laplacian image of k[th] level [3].

Where

$$I_{uk}(x,y) = \begin{cases} I_{dk}(x,y) & x = 1,3,5 \\ 0 & otherwise \end{cases} \tag{19}$$

Here, I_{uk} is up-sampled image of k[th] level, which can be achieved by interlacing zeros with the down sampled image I_{dk} of k[th] level and n represents the n[th] pixel of the image.

Laplacian based image fusion has two stages which are pyramid construction and image fusion. In the first stage, Laplacian pyramid is constructed for both EO and IR images from the respective Gaussian pyramids as shown in Figure 5.



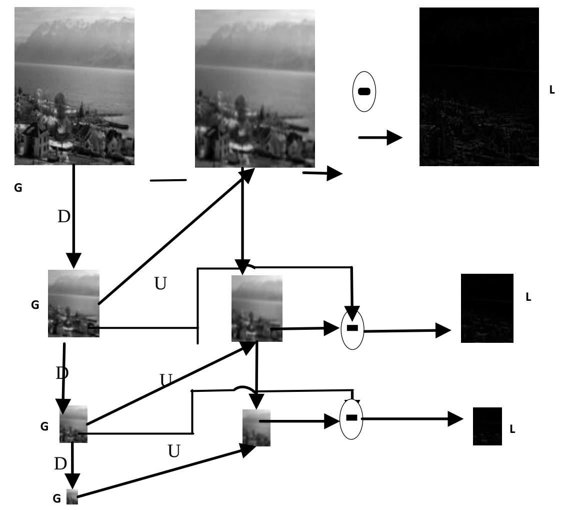


Figure 5: Laplacian pyramid construction

In second stage, fusion is performed for the final level images of Gaussian pyramids of both EO and IR images and average is taken from these two images. The resultant image is up-sampled and added with the next level of maximum image in continuous iterations till it reaches the first level of Laplacian pyramids as in reverse order. The final resultant image is considered as the fused image.

2.4 Discrete Wavelet Transform

Wavelet transform is a superset of Fourier transform. In Fourier theory, signal is decomposed into sines and cosines and in wavelet transform, the signal is projected on a set of wavelet functions. While Fourier transform provides good resolution in frequency domain, wavelet transform provides good resolution in both frequency and time domains. Discrete Wavelet Transform uses a discrete set of wavelet scales and translation and it decomposes the signal into mutually orthogonal set of wavelets.

In Discrete Wavelet Transform, the dilation factor is $a = 2m$ and translation factor is $b = n^2 m$, where m and n are integers. Wavelet transform of a 1-D signal f(x) is defined as

$$W_{a,b}(f(x)) = \int_{x=-\infty}^{\infty} f(x)\psi_{a,b}(x)dx \tag{20}$$

Scaling properties are described by the scaling function, which is used to construct the wavelets. The translation and dilation of mother wavelet is defined as,

$$\psi_{a,b}(x,y) = \frac{1}{\sqrt{a}}\psi\left(\frac{x-b}{a}\right) \tag{21}$$

Wavelet separately filters and down-samples the 2-D data (image) in horizontal and vertical directions. The input image $I(x,y)$ is filtered by low pass filter (L) and high pass filter (H) in horizontal direction and then down-sampled by a factor of two to create coefficient matrices $IL(x,y)$ and $IH(x,y)$. Then the coefficient matrices are both low pass filtered and high pass filtered in vertical direction and down sampled by factor of two, to create sub bands $ILL(x,y)$, $IHL(x,y)$, $ILH(x,y)$ and $IHH(x,y)$. $ILL(x,y)$ represents the approximation of input image $I(x,y)$. Then, $IHL(x,y)$, $ILH(x,y)$ and $IHH(x,y)$ represent the horizontal, vertical and diagonal information of the input image $I(x,y)$ respectively. The inverse 2-D wavelet transform is used to reconstruct the original input image I (x, y) from the sub bands $ILL(x,y)$, $IHL(x,y)$, $ILH(x,y)$ and $IHH(x,y)$. This involves column up-sampling and filtering using low pass and high pass filters for each sub images. Row up sampling and filtering with low pass and high pass filters and summation of all matrices would construct the original image $I(x,y)$ [4].

The wavelet coefficient matrices are achieved for both the input images by applying Discrete Wavelet transform (DWT) on each input image. The Wavelet coefficient matrix of each image contains approximation, horizontal, vertical and diagonal components. The fused wavelet coefficient matrix is achieved by applying fusion rules on both wavelet coefficient matrices. Finally, the Inverse discrete wavelet transform (IDWT) is applied on the fused wavelet coefficient matrix to obtain the fused image as shown in Figure 6.

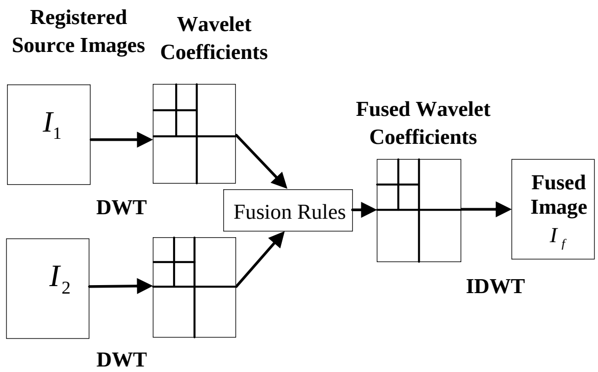


Figure 6: Wavelet based image fusion

3. PERFORMANCE EVALUATION METRICS

Usually, performance evaluation of fusion techniques is done by using a reference image, but here reference image is not available as it is a real time application. So the performance of fusion algorithms is evaluated by using No-reference metrics.

3.1 Standard Deviation

Standard deviation is a measure that is used to quantify the amount of variation of a set of data values. Low standard deviation indicates that 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 [4].

$$\sigma = \sqrt{\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left(I_f(x,y)-\mu\right)^2} \tag{22}$$

Where, M and N represents the number of rows and columns, μ is the mean of all pixel values in the image (I_f).

3.2 Entropy

Entropy is a measure of information content of an image. Entropy is sensitive to the noise an unwanted rapid fluctuations. The image with high information content would have high entropy [4].

$$He = -\sum_{i=0}^{L} h_{I_f}(i)\log_2 h_{I_f}(i) \tag{23}$$

Where, $h_{I_f}(i)$ is the normalized histogram of the fused image (I_f) and L is the number of frequency bins in histogram. The unit of entropy is bits/pixel.

3.3 Cross Entropy

Cross entropy is used to verify the similarity in information content between input and fused image. The low cross entropy indicates that the input and fused images are almost similar [4].

Overall cross entropy of the input images I_1, I_2 and the fused image I_f is

$$CE(I_1, I_2 : I_f) = \frac{CE(I_1;I_f)+CE(I_2;I_f)}{2} \tag{24}$$

Where $$CE(I_1;I_f) = \sum_{i=0}^{L} h_{i_1}(i)\log\left(\frac{h_{i_1}(i)}{h_{i_f}(i)}\right) \tag{25}$$

And $$CE(I_2;I_f) = \sum_{i=0}^{L} h_{i_2}(i)\log\left(\frac{h_{i_2}(i)}{h_{i_f}(i)}\right) \tag{26}$$

3.4 Spatial Frequency

Spatial frequency refers to the level of detail present in a stimulus per degree of visual angle. A scene with small details and sharp edges contains more high spatial frequency information than one composed of large coarse stimuli. This metric indicates the overall activity level in the fused image [4].

Spatial frequency criterion SF is: $SF = \sqrt{RF^2 + CF^2}$ (27)

Where row frequency of the image

$$RF = \sqrt{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=2}^{N}[I_f(x,y)-I_f(x,y-1)]^2} \tag{28}$$

and column frequency of the image

$$CF = \sqrt{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=2}^{N}[I_f(x,y)-I_f(x-1,y)]^2} \tag{29}$$

3.5 Fusion Mutual Information

Fusion Mutual Information indicates the degree of dependence of the fused image on the source images. The larger value of fusion mutual information implies better quality [4].

The joint histogram of source image $I_1(x,y)$ and $I_f(x,y)$ is defined as $h_{I_1 I_f}(i,j)$ and source image $I_2(x,y)$ and $I_f(x,y)$ is defined as $h_{I_2 I_f}(i,j)$. The mutual information is defined as follows,

$$FMI = MI_{I_1 I_f} + MI_{I_2 I_f} \tag{30}$$

Where

$$MI_{I_1 I_f} = \sum_{i=1}^{M}\sum_{j=1}^{N} h_{I_1 I_f}(i,j)\log_2\left(\frac{h_{I_1 I_f}(i,j)}{h_{I_1}(i,j)h_{I_f}(i,j)}\right)$$ (31) and

$$MI_{I_2 I_f} = \sum_{i=1}^{M}\sum_{j=1}^{N} h_{I_2 I_f}(i,j)\log_2\left(\frac{h_{I_2 I_f}(i,j)}{h_{I_2}(i,j)\,h_{I_f}(i,j)}\right) \qquad (32)$$

3.6 Fusion Quality Index

The range of this metric is 0 to 1 and one indicates the fused image contains all the information from the source images.

$$FQI = \sum_{w\in W} c(w)\left(\lambda(w)QI(I_1, I_f|w) + (1-\lambda(w))QI(I_2, I_f|w)\right) \qquad (33)$$

Where

$\lambda(w) = \frac{\sigma_{I_1}^{2}}{\sigma_{I_1}^{2} + \sigma_{I_2}^{2}}$ computed over a window and $C(w) = \max\left(\sigma_{I_1}^{2}, \sigma_{I_2}^{2}\right)$ over a window and $c(w)$ is normalized version of $C(w)$& $QI(I_1, I_f|w)$ is the quality index over a window for given source image and fused image [4].

3.7 Spectral Angle Mapper

Spectral Angle Mapper calculates angle in spectral space between the pixels and set of reference spectra for image classification based on spectral similarity.

$$\cos^{-1}\left(\frac{\vec{t}.\vec{r}}{\|\vec{t}\|\|\vec{r}\|}\right) \qquad (34)$$

Where r is reference spectra and t is spectra found in each pixel [4].

3.8 Average Contrast

Contrast is a visual characteristic that makes an object or its representation in an image distinguishable from other objects and the background. In visual perception, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view and higher contrast value is preferable [5].

$$C_{avg} = \frac{1}{(M-1)(N-1)}\sum_{x=1}^{M-1}\sum_{y=1}^{N-1}\left|\vec{C}(x,y)\right| \qquad (35)$$

Where, M and N represents the number of rows and columns of an image.

For an IR image, the contrast is the gradient calculated for the image as a single component:

$$\left|\vec{C}(x,y)\right| = \sqrt{\nabla^2 I(x,y)}$$

$$\nabla I(x,y) = \frac{\partial I(x,y)}{\partial x}\hat{i} + \frac{\partial I(x,y)}{\partial y}\hat{j} \qquad (36)$$

Where, ∇ = gradient operator

$I(x,y) =$ Image pixel value at (x,y)

Average gradient reflects the clarity of an image. It measures the spatial resolution in an image i.e. larger average gradient indicates a higher resolution. So, higher value of Average Contrast is an indication of better image quality.

For a color image, the color contrast is given by the average of gradients of Red, Green and Blue considered individually as follows:

$$\left|\vec{C}(x,y)\right| = \sqrt{\frac{\nabla^2 R(x,y) + \nabla^2 G(x,y) + \nabla^2 B(x,y)}{3}} \qquad (37)$$

3.9 Average Luminance

Luminance describes the amount of light that passes through, or is emitted from a particular area, and falls within a given solid angle. It indicates how much luminous power will be perceived by an eye looking at the surface from a particular angle of view. Luminance is thus an indicator of how bright the surface will appear [5].

$$L_{avg} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_f(x,y) \qquad (38)$$

For color image,

$$L_{avg} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}\frac{R(x,y) + G(x,y) + B(x,y)}{3} \qquad (39)$$

Higher luminance value represents the higher brightness value of an image.

3.10 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 zero and one [5].

$$E = \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} g(i,j)^2 \qquad (40)$$

3.11 Homogeneity

Homogeneity is a condition in which all the constituents are of the same nature. In image processing, Homogeneity returns a value that measures the closeness of the distribution of elements in the Gray Level Co-occurrence Matrix (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 [5].

$$I_{\text{hom}} = \sum_{i=1}^{\infty}\sum_{j=1}^{\infty}\frac{g(i,j)}{1+|i-j|} \qquad (41)$$

4. HARDWARE SETUP

Both imaging sensors are operated using +12 V wall adaptor or battery. The outputs of the cameras are connected to the frame grabber through two RS-170 ports respectively. The hardware setup used for developing the image fusion techniques is shown in Figure 7.

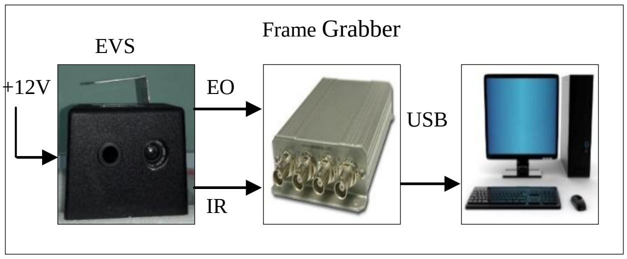


Figure 7: Hardware Setup for EVS Image Fusion

4.1 LWIR Specifications

The LWIR incorporates an uncooled 324x256 pixels micro bolometer. It has an internal heater to defrost its protective window. The LWIR has technical specifications as given in the Table 1.

4.2 EO Color Camera

The EO Camera with CMOS sensor has technical specifications as given in the Table 2.

Table 2: Technical Specifications of EO camera

Technical Specifications	
Detector Type	CMOS ¼''
Field of View	38° (H) x 25° (V) with 6.8 mm lens
Output Formats	NTSC/PAL Analog, Raw RGB, 1.0Vpp /75Ω Composite Video Signal
Power Supply	Digital Core 5V DC ~ 24VDC
Board Dimensions	32mm x 32mm (without lens)
Power Requirement	<750mW (@5V)
Synchronization	Internal
Resolution	400 TV Lines
S/N Ratio	38dB
Dynamic Range	100dB
Pixel Size	6µm x 6µm
Image Area	4.752 mm x 3.036 mm
Min Illumination	1 Lux (F1.2)

4.3 Sensoray Frame Grabber

A four-channel Sensoray Frame Grabber (2255) is used for capturing image frames from both the cameras at a desired frame rate. The maximum frame rate that can be achieved with this frame grabber is 60 frames/sec, when single channel is used. When two channels are used, the frame rate gets reduced to 30 frames/sec, and when all four channels are used the frame rate further gets reduced to 15 frames/sec. Here, two channels are used and so the maximum frame rate achieved is 30 frames/sec. The digitized output from the frame grabber is given to the computer by using USB cable.

4.4 System Requirements

A computer with the specification mentioned in Table 3 is needed to run this application.

Table 3: System Requirements

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
5	Frame Grabber driver	Direct show windows driver version 1.1.10 should be installed
6	Visual Studio	2008 or higher version

5. RESULTS AND DISCUSSIONS

Fusion methods are implemented by using Open Source Computer Vision (OpenCV) image processing library in Visual Studio platform as Win32 Console application and the C++ programming language is used to implement the methods. This application is capable of capturing real time video data from two cameras and simultaneously fusing both the camera outputs into a single video data. Once the application is started, the user has to select fusion method from the given options and also the mode of display as 0 for normal mode and 1 for full screen mode as shown in Figure 8.

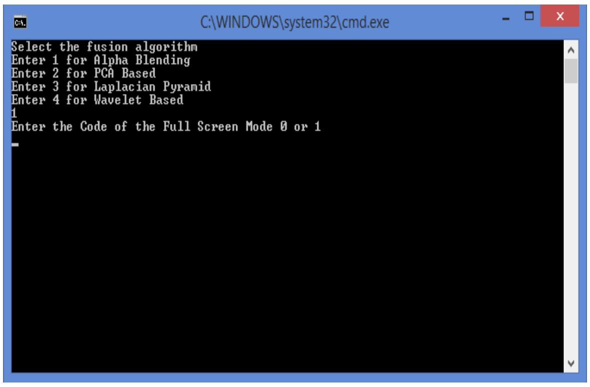


Figure 8: User-interface for selecting the mode of display

The advantage of fused output over input image is verified under different environmental conditions such as day time, night time, foggy etc. As IR camera is temperature sensitive, hot areas on the IR images are highlighted including human body. So, during low light condition when EO camera cannot capture the scene properly, IR camera would be helpful to capture the actual scene. So the intention of the fusion techniques is to merge features from both the camera output images and give a featured image which contains all the necessary information.

5.1 Image Fusion for Still Images

The initial development of image fusion techniques is started with the still EO and IR images in same Field of View (FOV). So image registration is not required since both the input images have same field of view. The performance of fusion techniques for these still images is evaluated using fusion evaluation metrics given in Table 4. The reference still input image taken to perform image fusion is shown in the Figure 9.

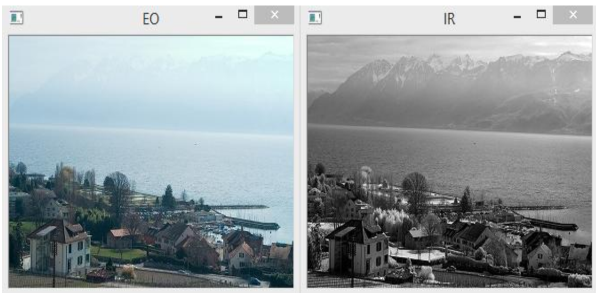
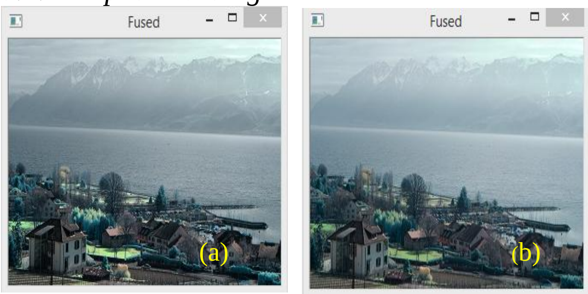


Figure 9: (a) EO Image, (b) IR Image

5.1.1 Alpha Blending



Due to the fog, the mountain is not visible in the EO image as shown in Figure 9 (a). At the same time because of the weather penetrating nature of the IR camera, the mountain is visible in IR image, but color information is not there as shown in Figure 9 (b). The fused images for various alpha values are shown in the Figure 10.

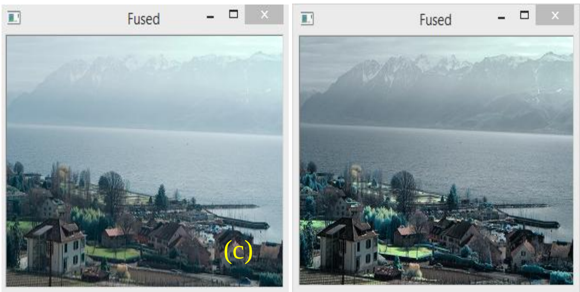


Figure 10: (a) Fused image when Alpha is 0.2, (b) Fused image when Alpha is 0.5, (c) Fused image when Alpha is 0.7

5.1.2 Principal Component Analysis

The difference between the Alpha blending and PCA technique is that the PCA has the capability to determine the weightage to be given to the input images dynamically based on the Eigen vectors of the input images respectively.

The fused image for the PCA technique is shown in Figure 11.

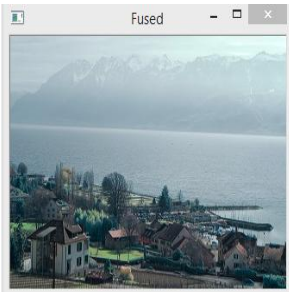


Figure 11: Fused image using PCA method

5.1.3 Laplacian Transform

Laplacian pyramid technique is edge sensitive, high weightage would be given to the edges of all the objects in input images. The fused image for various levels achieved in the Laplacian pyramid is shown in the Figure 12.

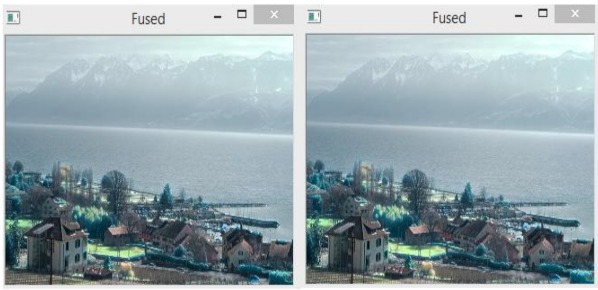


Figure 12: (a) Fused image when 1 level is achieved, (b) Fused image when 2 levels are achieved, (c) Fused image when 3 levels are achieved, (d) Fused image when 4 levels are achieved

5.1.4 Discrete Wavelet Transform

The fused image for one level achieved in wavelet transform is shown in Figure 13.

5.2 Image fusion for Real Time Images

Fusion techniques are implemented for still images obtained from real time camera and performance of the fusion techniques for the real time images is evaluated using fusion performance metrics given in Table 5.

5.2.1 Alpha Blending

The frame rate achieved for Alpha blending fusion method is 29 frames per second. It is tested and is concluded that the frame rate is consistent for all the Alpha values. For the outputs shown in the Figures 14 and 15, the alpha value is taken as 0.5. So, equal weightage is given to both the input images in the fused image. Here, the weightage is to be determined by the user and it cannot be modified once the application is started to run. During day time, the EO camera's performance is better than the IR camera, even though the high temperature portions are highlighted in the IR image as shown in Figure 14 (b). So, the fused image contains most of the information from EO and temperature highlighted information from IR as shown in Figure 14 (c).

Figure 13: Fused Image when one level of wavelet transform is achieved

(a)

(b)

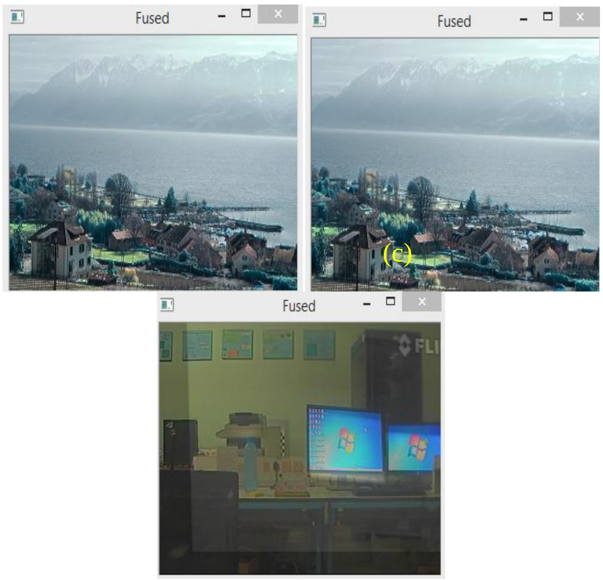


Figure 14: (a) EO, (b) IR, (c) Fused image in day effect

During night time, the IR camera's performance is better than the EO camera. As EO camera doesn't work without light source. So, the fused image contains most of the information from IR and some of the color information from EO as shown in Figure 15 (c).

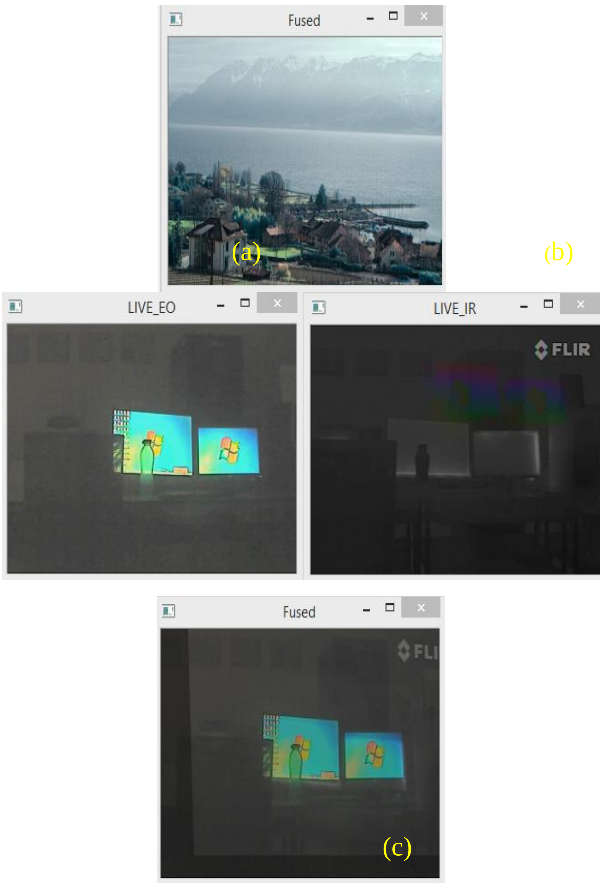


Figure 15: (a) EO, (b) IR, (c) Fused image in night effect

5.2.2 Principal Component Analysis

Frame rate achieved for PCA based fusion method is 20 frames per second. During day time, the PCA technique gives high weightage to EO image as shown in Figure 16 (c). So the fused image contains most of the information from EO and temperature highlighted information from IR.

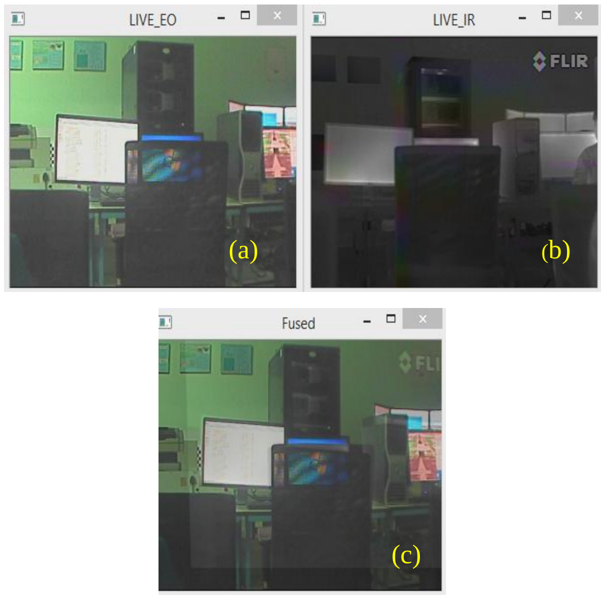


Figure 16: (a) EO, (b) IR, (c) Fused image in day effect

During night time, the PCA technique gives high weightage to the IR image as shown in Figure 17 (c). So the fused image contains most of the information from IR and color sensitive information from EO.

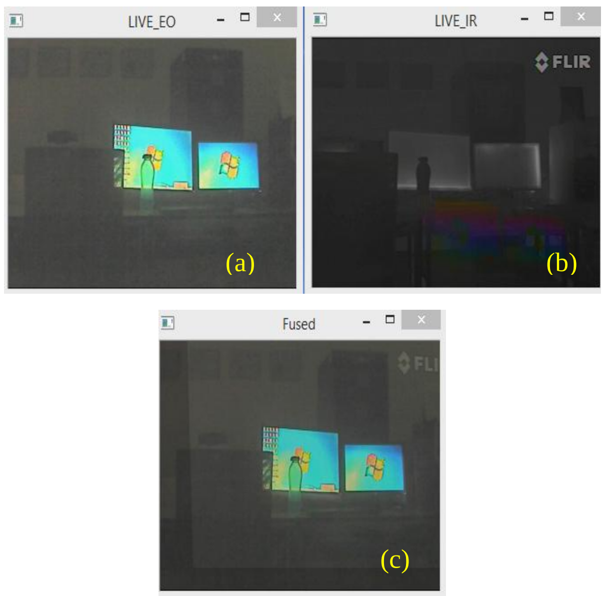


Figure 17: (a) EO, (b) IR, (c) Fused image in night effect

5.2.3 Laplacian Pyramid

The number of levels of image pyramid is limited to the size of the input image. The frame rate variation based on the number of levels is shown in Table 6.

Table 6: Frame Rate variation

Number of Levels	Frames/Sec	Time (Milliseconds)
1	22	45
2	21	46
3	21	47
4	20	48

During day time, the Laplacian pyramid technique gives high weightage to the edges of the EO image as shown in Figure 18(c). So the fused image contains most of the edge information from EO and temperature highlighted edge information from IR.

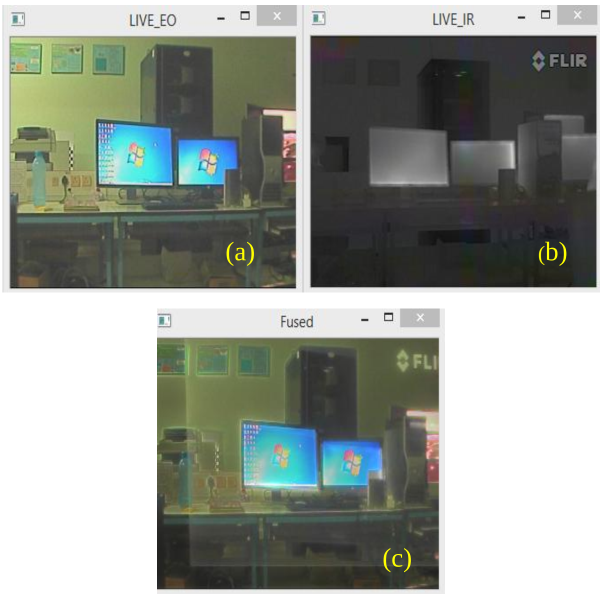
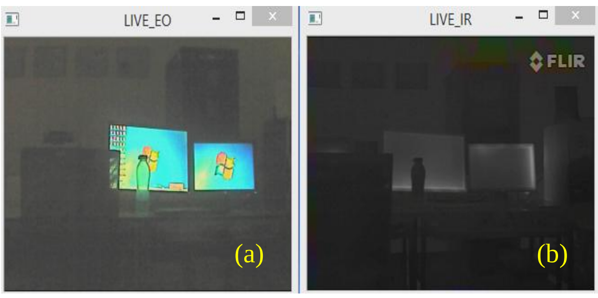


Figure 18: (a) EO, (b) IR, (c) Fused image in day effect

During night time, the Laplacian pyramid technique gives high weightage to the IR edges image as shown in Figure 19 (c). So the fused image contains most of the edge information from IR and color sensitive edge information from EO.



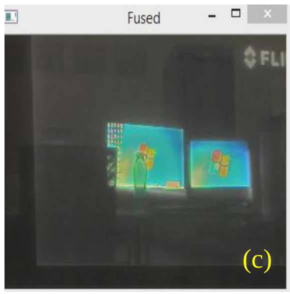


Figure 19: (a) EO, (b) IR, (c) Fused image in night effect

5.2.4 Discrete Wavelet Transform

Wavelet based image fusion method is time consuming process because it is totally based on pixel level operations. So because of its speed limitation only one level of wavelet transform is implemented. The frame rate achieved for Wavelet based fusion method is 12 frames per second. During day time, the Wavelet technique gives high weightage to the horizontal, vertical and diagonal information of the EO image as shown in Figure 20 (c). So the fused image contains most of the information from EO and temperature highlighted information from IR. During night time, the Wavelet technique gives high weightage to the horizontal, vertical and diagonal information of IR edges as shown in Figure 21 (c). So, the fused image contains most of the information from IR and color sensitive information from EO.

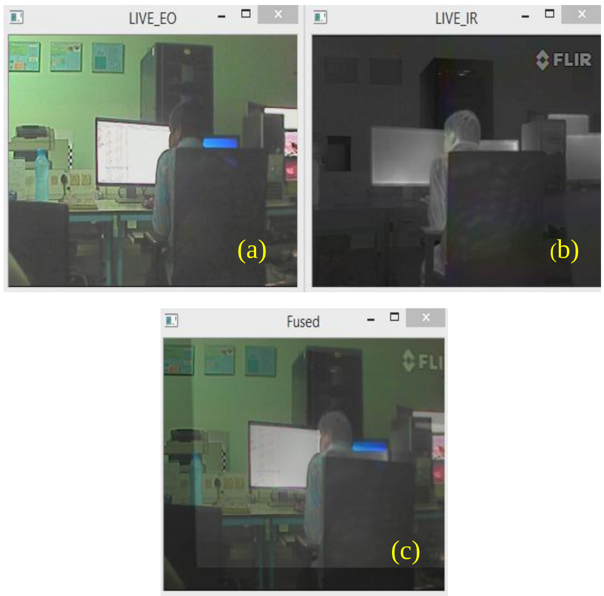
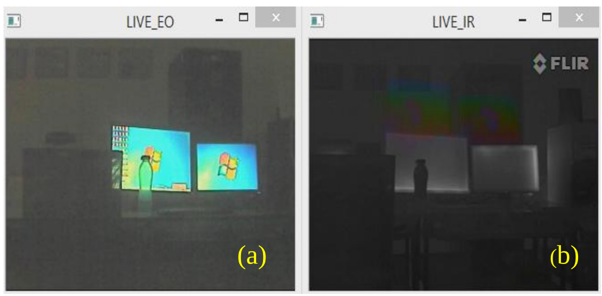


Figure 20: (a) EO, (b) IR, (c) Fused image in day effect



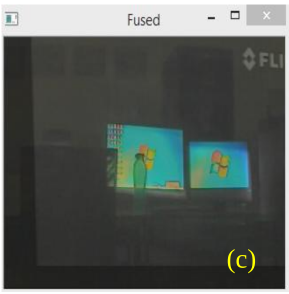


Figure 21: (a) EO, (b) IR, (c) Fused image in night effect

6. CONCLUSION

Four real-time image fusion techniques viz., Alpha Blending, Laplacian Pyramid, PCA and DWT are implemented and tested. The performance of these methods is evaluated using fusion performance metrics. As per the results of the fusion performance metrics, it is concluded that the Laplacian pyramid based fusion method provides better results compared to the other fusion methods. This can be implemented in aircrafts using EVS, so that the fusion of EO and IR images results in an enhanced image that helps improve pilot's situational awareness.

7. REFERENCES

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Table1: Technical Specifications of LWIR camera

Technical Specifications	
Detector Type	Focal Plane Array (FPA), uncooled micro bolometer 324 x 256 pixels
Spectral Range	8 to 14µm
Field of View	36° (H) x 27° (V) with 19 mm lens
Spatial resolution	2 mrad
Thermal Sensitivity	100 mK at +25°C
Image Frequency	8.3 Hz PAL
Focus	Automatic (25 m to infinity)
Video output	Analog, CCIR/PAL composite video, 75Ω
Automatic Heater	When window temperature is below +4°C
Input Power	6 - 16 V DC
Power Consumption	2W quiescent, 6 W max (with window heater on)
Operating temperature range	-40°C to +80°C
Encapsulation	Hermetically sealed enclosure
Camera weight	360g
Camera Size	57.4 mm x 56.1 mm x 71.4 mm excluding connector which protrudes an additional 28.7 mm

Table 4: No Reference Fusion Performance Metrics for still images

Name of the Metric	**Alpha Blending**	**PCA**	**Laplacian Pyramid**	**DWT**
Standard Deviation	0.2401	0.2441	0.2174	0.2378
Entropy	7.6245	7.6026	7.5604	7.5977
Cross Entropy	0.2016	0.1978	0.1977	0.2045
Spatial Frequency	0.0862	0.0829	0.1008	0.0646
Fusion Mutual Information	2.6144	2.6622	2.5527	2.6194
Fusion Quality Index	0.7723	0.7510	0.7207	0.7098
Spectral Angle Mapper	299.5831	341.3087	245.8894	666.1811
Average Contrast	0.0185	0.0177	0.0208	0.0144
Average Luminance	0.5427	0.5540	0.5954	0.5426
Energy	0.1261	0.1384	0.1401	0.1397
Homogeneity	0.8887	0.8980	0.8862	0.9205

Table 5: No Reference Fusion Performance Metrics for real-time images

Name of the Metric	**Alpha Blending**	**PCA**	**Laplacian Pyramid**	**DWT**
Standard Deviation	0.1415	0.1510	0.1595	0.1394
Entropy	6.7589	6.7485	6.9666	6.7501
Cross Entropy	0.0072	0.0055	0.0112	0.0349
Spatial Frequency	0.0348	0.0445	0.0376	0.0315
Fusion Mutual Information	3.8171	3.3831	3.4875	3.7547
Fusion Quality Index	0.8870	0.8697	0.8926	0.8893
Spectral Angle Mapper	2068.2	1730.3	1463.3	2850.3
Average Contrast	0.0070	0.0081	0.0082	0.0068
Average Luminance	0.3087	0.3590	0.3544	0.3079
Energy	0.2686	0.2216	0.2289	0.2719
Homogeneity	0.9667	0.9518	0.9618	0.9690