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Enhancement Infrared-Visible Image Fusion Using the Integration of Stationary Wavelet Transform and Fuzzy Histogram Equalization

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Abstract

Image fusion is the process of merging two or more images to obtain complementary features from source images. Imaging techniques in real-world applications provide images with a different texture than the other, where visible images provide spatial information while infrared images provide spectral information. Hence the importance of image fusion, which aims to combine spatial and spectral information in one image. Wavelet transform is a method used in the process of image fusion as feature extraction, and images are decomposed into a series of low and high-frequency subbands. Wavelet transform provides images with good representation and is a multi-resolution analysis. However, the resulting image after the wavelet-based fusion process has low-quality information which is blurry. In addition, infrared images by their nature suffer from blur. In this paper, a novel image fusion method has been proposed to enhance visible-infrared image fusion using the integration of stationary wavelet transform and fuzzy histogram equalization. Firstly, input the images. Secondly, preprocessing the images. Thirdly, stationary wavelet transform has been used for decomposing the images in 2 levels. Fourthly, Averaging fusion rule is used for fusing the approximation coefficients. Finally, fuzzy histogram equalization is used in reconstructing the level 2 process to obtain the final enhanced image. The performance of the proposed method is evaluated by using seven metrics that proved the superiority of the proposed method compared to the standard methods.

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Keywords: Image Fusion; Wavelet Transform; Multimodal; DWT; SWT; Visible and Infrared; Fuzzy Histogram Equalization.

1. Introduction

The imaging technique of the infrared (IR) has usually been embraced for observing objectives due to its ingrained picturing features founded on the thermic ray divergence of targets. IR images have a powerful ability to be resistant to the bad weather situations such as rain, fog, and low illumination. However, IR images typically have low resolution and indistinct textures detail. Per contra, visible images usually can have the optical information detailed and better resolution. However, it is hard to recognize the objectives fine, due to the visible picturing system can simply be affected by bad weather [1]. while, the visible and IR images can equip the fused images with complementary information for the same sight, and the fused image can enhance the visual performance for machine vision and human visual realization. Image fusion is the process of fusing the elements of the image from multi-images to obtain a sole image with more information compared to the entered images [2]. These images are taken by using a single sensor or by using multiple sensors of different modalities, depending on the application [3]. Image fusion is split into three categories which are pixel, feature, and decision level. Pixel level is considered as the low level where images fused with the current pixels without pre-estimated and recognition. Which is predicted to be further information to the machine percept or human percept or as a comparison to the original images. For this feature, pixel-level image fusion had shown remarkable accomplishments in medical imaging, night vision, and remote sensing applications [4]. Image fusion technique has been used commonly in numerous areas such as medical, military, security, and remote sensing [5]. Multimodal image fusion fused various images taken by different sensors such (as CT and MRI, visible and infrared, or panchromatic and multispectral satellite images). The visible image mirrors the plenty of detailed textiles and the background information of the sight with better spatial resolution. conversely, the infrared image reveals the contours of unclear objects beneath low lightness. for this reason, the fusion of visible and infrared images has an important role in many fields such as object pursuit, target determination and regional alter discovery [6]. Image fusion can apply in two domains, spatial and frequency domains. The resultant image from the fusion in the spatial domain does not contain Spectral information and has spatial distortions. Consequently, transform fusion methods have been used to outdo the negatives of spatial fusion [7]. Image de-blurring or image enhancement is an important issue in many applications of imaging a real sight or object [8]. Wavelet transform (WT) is a mathematical tool that has the localized analysis ability of the time domain and frequency domain [9], and the strategy of stationary wavelet transform (SWT) decomposition is the same as WT. The rest of the paper has been structured as follows.: Section 2 proffers the literature review and the aim of the study. Section 3 proffers the methodology of the paper which contains the theoretical side and performance metrics used to evaluate the proposed method. Section 4 proffers results and discussion followed by section 5 which presents the conclusion.

Nomenclature

WT	Wavelet Transform	CT	Computed Tomography
DWT	Discrete Wavelet Transform	MRI	Magnetic Resonance Imagining
SWT	Stationary Wavelet Transform	his	Histogram
DT-CWT	Dual Tree-Complex Wavelet Transform	I	Intensity
DCT	Discrete Cosine Transform	H	Hue
IHS	Intensity, Color, And Saturation Transform	S	Saturation
FHE	Fuzzy Histogram Equalization	*cA*	Approximation Coefficients
cH	Horizontal Coefficients	*cV*	Vertical Coefficients
cD	Detailed Coefficients	*N*	Columns*
M	Rows	IR	Infrared
VW	Variance Of Wavelet Coefficients	*CF*	Contrast Focus Measure
SF	Spatial Frequency Measure	*HE*	Histogram Entropy
GV	Gray Level Variance	*GE*	Gradient Energy
SW	Sum Of Wavelet Coefficients	*IDWT*	Inverse Discrete Wavelet Transform
LL	Low Low	*ISWE*	Inverse Stationary Wavelet Transform
LH	Low High	*HL*	High Low
HH	High High	ψ	Wavelet Function
μ	Mean	Ω	Sample Space
x[n]	Signal	↓	Decimated Process

2. Literature review

There are numerous image fusion enhancement methods have been presented. The authors in [10], proffered a method to improve the fusion of infrared and visible images based on discrete wavelet transform (DWT). In this method, the visible and infrared images are decomposed by DWT, and low-frequency and high-frequency subbands will be obtained. Regional energy has been used as a fusion rule for fusing the low-frequency coefficients, and the weighted sum of the variance between adjacent coefficients as a fusion rule for fusing the high-frequency coefficients. An inverse of DWT has been used for obtaining the final image. The author in [11], presented a fusion method based on dual tree-complex wavelet transform (DT-CWT) and focus filter, for fusing many types of images. In this method, images are enhanced by a focus filter before the fusion process. Focus filters is consisting of two filters, which are the wiener algorithm and sharpening filters. Averaging and maximum select fusion rules are used for fusing the coefficients and gaining the final fused image by the inverse of DT-CWT. The authors in [12], proffered a study for visible-infrared image fusion enhancement. This method is based on the locally important areas of the infrared image only. In a three-step approach. First, the segmented regions of the infrared image are extracted. Then, image fusion is applied to the segmented areas. Finally, contour lines are used to improve the quality of the results image. Entropy and mutual information performance metrics have been used to evaluate the proposed method. The authors in [13], presented a new method for multi-focus image fusion. In this method, the images are firstly decomposed by DWT to obtain the low-frequency subbands and the high-frequency subbands. Variance has been used to fuse low-frequency subbands and weighted fusion rule to fuse the high-frequency subbands. Finally, the inverse of DWT has been used to obtain the final image. Entropy and standard deviation performance metrics have been used to evaluate the proposed method. The authors in [14], presented a method for multi-focus image fusion. In this method, a hybrid sharpening method has been used that blends laplacian filter with discrete cosine transform (DCT) for applying on the entered images as preprocessing step before the fusion process based on SWT. And using an unsharp mask with SWT-based image fusion. The performance of the proposed method is evaluated by comparing it with four traditional methods using performance metrics. The authors in [15], presented a method to enhance visible-infrared image fusion by using the intensity, color, and saturation transform (IHS) and discrete wavelet transform (DWT). In this method, the two images are first analyzed by (IHS) to obtain the components of intensity (I), hue (H), and saturation (S). The intensity components are then decomposed by DWT for obtaining the four subbands' frequencies. The fusion algorithm is adopted based on the spatial domain for low-frequency sub-bands and the high-frequency sub-bands' window-based average gradient. Component (I) is reconstructed by the inverse of (IHS) with the (H) and (S) components of the visible images to get the final image. Entropy, gradient energy, and mutual information performance metrics have been used to evaluate the proposed method.

Researchers have presented several methods for visible-infrared image fusion, and these methods are given good results. But still, there is a scope for enhancing the quality of visible-infrared image fusion. In this work, a novel method has been presented for visible-infrared image fusion enhancement using the integration of stationary wavelet transform (SWT) and fuzzy histogram equalization (FHE).

3. Methodology

3.1. Discrete Wavelet Transform

Discrete Wavelet Transform (DWT) is an execution of the wavelet transform (WT) by using dyadic measures and positions [16]. Signals in DWT are firstly passing through low pass then high pass filters and downsampled by a factor of two to gain the wavelet coefficients. The source image is divided into various scales at four low subbands (LL), high low (HL), low high (LH), and high (HH). with (one approximation and three detailed images which are vertical, horizontal, and diagonal) [17]. Discrete wavelet coefficients can be obtained mathematically by the equation as mentioned in [17], see Figs. 1 & 2:

$$C(a,b)=\sum_{n=-\infty}^{+\infty} x[n]\psi_{a,b}[n] \quad (1)$$

Where, $x[n]$ represents the input signal, $\psi_{a,b}[n]$ the mother wavelet which can be in mathematical expressed by the equation as pointed out in [17]:

$$\psi_{a,b}[n]=2^{-\frac{a}{b}}\psi[2^{-a}n-b] \tag{2}$$

Where a and b represent the scale indicator and position indicator respectively.

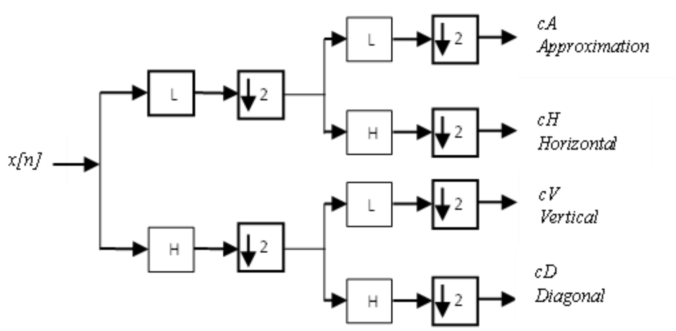

Fig. 1. Decomposition process of the discrete wavelet transform with four subbands

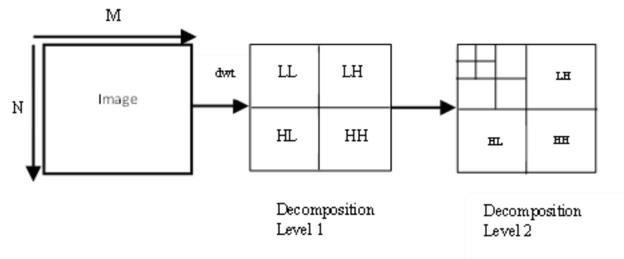

Fig. 2. Image decomposition-based discrete wavelet transforms in 2 level

DWT-based image fusion can be implemented through three main stages, first stage: converted the input images to the transform domain by using one of the forms of the wavelet transform. Second, the resultant subbands are fused by the fusion rules. Lastly, the image obtained by the reconstructing process of the wavelet transform. Fig. 3 illustrates DWT-based image fusion.

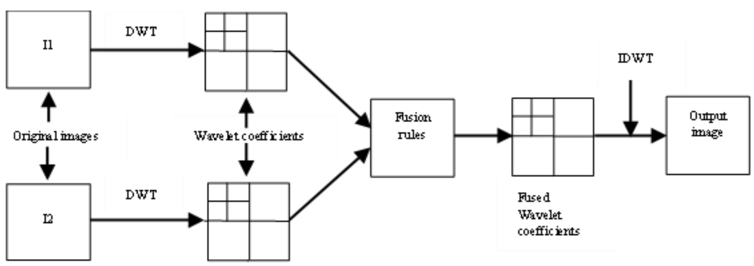

Fig. 3. Illustrate the process of image fusion based on discrete wavelet transform

3.2. Stationary Wavelet Transform

Stationary Wavelet Transform (SWT) method has been introduced via (Holschneider) in 1989 it is widely recognized as "algorithm à trous" in French. in SWT, the signal is passed with a low pass filter and high pass filter in the same manner as DWT but there is no downsampling process applied to gain wavelet coefficients approximated and detailed coefficients. By inserting zeros at each level of the transform [18]. DWT suffers from shift variance and directional selectivity. Therefore, SWT was presented which provides translation-invariant [19].
Fig. 4. illustrate signal decomposition-based SWT with the four subbands coefficients cA, cH, cV, and cD which represent Approximation, Horizontal, Vertical and Diagonal respectively.

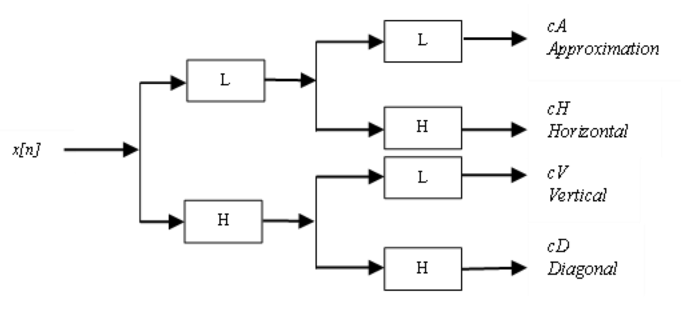

Fig. 4. Decomposition process of stationary wavelet transform with four subbands

3.3. Fuzzy Histogram Equalization

Fuzzy histogram equalization (FHE) is an image contrast enhancement technique. FHE was designed based on fuzzy logic to deal with the inaccuracy of gray-level values in an efficient way [20]. FHE is divided into two operations: first, counting the fuzzy histogram based on fuzzy set theory to handle the intensity values in the best way. Second, partitioned the fuzzy histogram from the first operation is into two sub-histograms depending on the median value of the source image and then each sub is equalized in an independent form to preserve the brightness values of the image [21]. FHE can be considered as a set of real numbers based on fuzzy membership function as his(i) and $i \in \{0,1,\dots,k-1\}$ and can be in a mathematical expression as mentioned in [22]:

$$I=his(i)+\sum_{i}\sum_{j}\mu_{\sim f(i,j)i},k\in[a,b]$$

Where, $\mu_{\sim f(i,j)i}$ represent the membership triangular function can be defined as:

$$\mu_{\sim f(i,j)i}=\max\left(0,1\frac{|I(x,y)-i|}{4}\right) \quad (4)$$

And, [a,b] represent the membership function domain

3.4. Proposed method

Enhancement of visible-infrared image fusion using the integration of stationary wavelet transform (SWT) and fuzzy histogram equalization (FHE) has been proposed to improve the quality of the resulting image. The steps of the proposed method are as the following:
Step 1- Read images let's say image 1 and image 2.
Step 2 - converting each image into a gray level as preprocessing step.
Step 3 - Images decomposition to obtain LL1, LH1, HL1, and HH1 coefficients using SWT in level 1.
Step4 - Decomposition the approximation coefficient LL1 from level 1 to obtain LL2, LH2, HL2, HH2 coefficients in level 2.
Step 5 - Averaging fusion rule has been used for fusing LL2 approximation coefficients from the two images in level 2 and using the addition process for fusing the three detailed coefficients LH2, HL2, and HH2 in level 2.
Step 6 - fused LL1 coefficients from the two images in level 1 by using averaging fusion rule and fusing LH, HL HH in level 1 by using the addition process.
Step7 - inverse process of SWT has been used to reconstruct LL2, LH2, HL2, and HH2 coefficients in level 2.
Step8 - filtering the approximation fused coefficients LL2 which is reconstructed in step7, by fuzzy histogram equalization (FHE) enhancement technique before reconstructing for level 1.
Step9 - the inverse process of SWT has been used for reconstructing LL1, LH1, HL1, and HH1 coefficients in level 1, for obtained the final enhanced image.
The following are the steps of the presented algorithm for the image fusion method using SWT and FHE for two levels (Fig. 5):
Step 1- Read the input Images-Image 1 and Image 2.
Step 2 - convert each image into the gray level.
Step3 - Image decomposition using SWT in level 1:

```
[AC1L1, HC1L1, VC1L1, DC1L1] = swt2(image1)
[AC2L1, HC2L1, VC2L1, DC2L1] = swt2(image2)
```

Step4 - Image decomposition using SWT in level 2:

```
[AC1L2, HC1L2, VC1L2, DC1L2] = swt2(A1L1);
[AC2L2, HC2L2, VC2L2, DC2L2] = swt2(A2L1);
```

Step5 – image fusion at level 2

```
ACfL2 = 0.5*(AC1L2+AC2L2)
D = (abs (HC1L2)-abs (HC2L2))>=0;
HCfL2 = D.*HC1L2 + (~D). *HC2L2;
D = (abs (VC1L2)-abs (VC2L2))>=0;
VCfL2 = D.*VC1L2 + (~D). *VC2L2;
D = (abs (DC1L2)-abs (DC2L2))>=0;
DCfL2 = D.*DC1L2 + (~D). *DC2L2;
```

Step6 - image fusion at level 1

```
D = (abs (HC1L1)-abs (HC2L1))>=0;
HCfL1 = D.*HC1L1 + (~D). *HC2L1;
D = (abs (VC1L1)-abs (VC2L1))>=0;
VCfL1 = D.*VC1L1 + (~D). *VC2L1;
D = (abs (DC1L1)-abs (DC2L1))>=0;
DCfL1 = D.*DC1L1 + (~D). *DC2L1;
```

Step7 - fused image can be obtained by:

```
ACfL1 = iswt2(ACfL2, HCfL2, VCfL2, DCfL2);
Step7- Applying FHE on ACfL1
ACfL1= FHE(ACfL1);
```

Step8- the final Fused image is reconstructed by:

```
Fused image = iswt2(ACfL1, HCfL1, VCfL1, DCfL1);
```

Where ACL is approximation coefficients and HCL, VCL, and DCL are detail coefficients

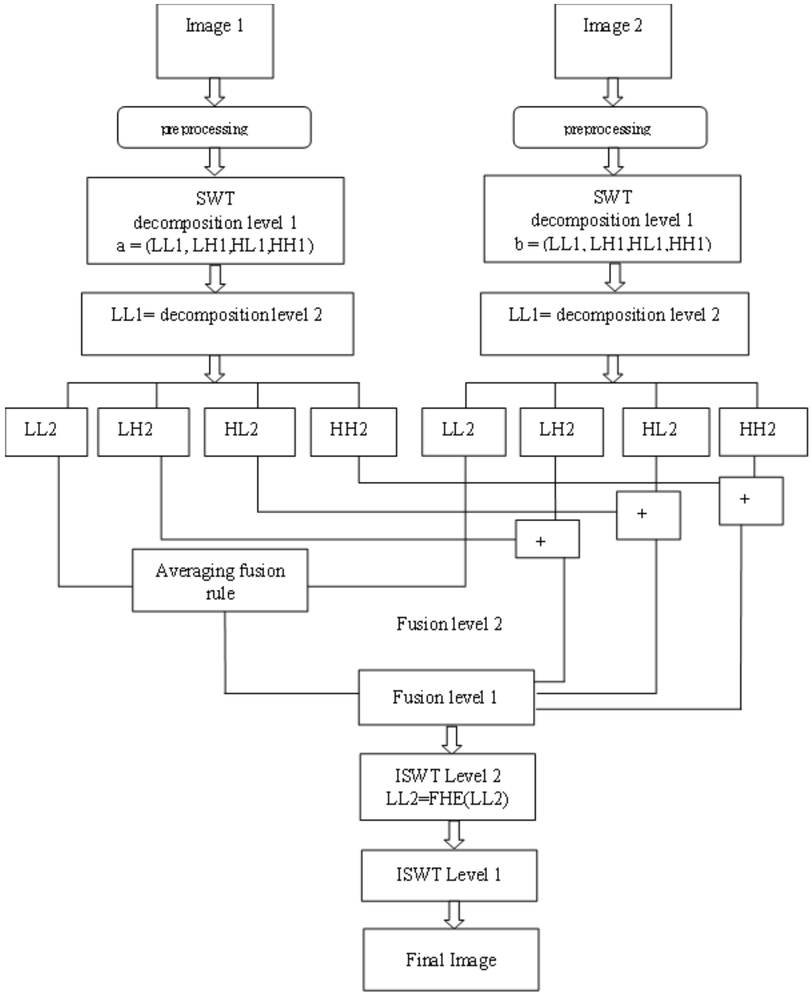

Fig. 5. Illustrate the structure of the proposed algorithm

3.5. Performance Evaluation Metrics

The following are some of the metrics utilized to evaluate the performance of the proposed image fusion method and traditional image fusion methods:

3.5.1. Spatial frequency measure

Spatial frequency estimates the overall activity level in an image. The spatial frequency scale can be defined as pointed out in [23]:

$$SF(x,y)=\sqrt{(rf)^2+(cf)^2} \quad (5)$$

Where rf represent the frequencies of the rows, cf represents the frequencies of the columns and they can be expressed as pointed out in [23]:

$$rf=\sqrt{\frac{1}{mn}\sum_{i=1}^{m}\sum_{j=2}^{n}[f(i,j)-f(i,j-1)]^2} \quad (6)$$

$$cf=\sqrt{\frac{1}{mn}\sum_{i=1}^{n}\sum_{j=2}^{m}[f(i,j)-f(i-1,j)]^2} \quad (7)$$

3.5.2. Contrast Focus Measure

The contrast meter is used to measure the focus of the image where sharp images are of high contrast. The contrast meter can be obtained by the following equation as mentioned in [23]:

$$CF(x,y)=\sum_{m=x}\sum_{n=y}|I(x,y)-I(m,n)| \quad (8)$$

3.5.3. Gradient energy

The Gradient energy metrics are a focusing measure used for the computation of the energy of image gradient. The Gradient energy can be obtained mathematically by the following equation as mentioned in [23]:

$$GE(x,y)=\sum_{(m,n)\in\Omega(x,y)} I_X(m,n)^2+I_y(m,n)^2 \quad (9)$$

3.5.4. Histogram Entropy

A measure of evaluating the quantity of information included in a gray scale image. elevated entropy in the image denotes an increase in the image information. Entropy can be defined as pointed out in [23]:

$$HE=\sum_{k=0}^{K-1} P_i \log P_i \quad (10)$$

Where, K is representing the whole grey level, P_i,(i=1, 2, …, K-1) is the probability distribution.

3.5.5. Gray level variance

The Gray level variance operator is used to measure the contrast and if the image has high contrast, the standard deviation value is high. The standard deviation formula is defined mathematically as pointed out in [23]:

$$GV=\sqrt{\frac{1}{M*N}\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j)-\mu)^2} \quad (11)$$

Where, $I(i,j)$ the fused image, μ indicate the mean, M, N number of rows and columns respectively.

3.5.6. Sum of Wavelet Coefficients

The Sum of wavelet coefficients counts the focus degree of the improved image using the sum of coefficients of the wavelet. mathematically Can be defined as [23]:

$$SW=\sum_{(i,j)\in\Omega_D} abs(W_{LH1}(i,j))+abs\big(W_{HL1}(i,j)\big)+abs(W_{HH1}(i,j)) \quad (12)$$

Where, Ω_D is the corresponding of the neighborhood $(\Omega(i,j))$ of the enhanced image elements $f(i,j)$.

3.5.7. Variance of Wavelet Coefficients

The variance of wavelet coefficients counts the focus degree of the improved image by using the variance of coefficients of the wavelet. mathematically Can be defined as [23]:

$$VW=\sum_{(i,j)\in\Omega_D}(CW_{LH1}(i,j)-\mu_{LH1})^2+\sum_{(i,j)\in\Omega_D}(CW_{HL1}(i,j)-\mu_{HL1})^2+\sum_{(i,j)\in\Omega_D}(CW_{HH1}(i,j)-\mu_{HH1})^2 \quad (13)$$

Where, Ω_D is the corresponding overture Ω in DWT Subbands, and μ_{LH1}, μ_{HL1}, μ_{HH1} indicates the average value of the respective DWT Subbands within Ω_D.

4. Results and Discussion

In this paper, the enhancement of visible-infrared image fusion using the integration of stationary wavelet transform (SWT) and fuzzy histogram equalization (FHE) has been presented. The results that have been obtained showed the effectiveness of the proposed method. Traditional methods DWT and SWT have been used for comparison of the results and the performance of the experiment has been evaluated by using the focus operators which are: Spatial frequency measure (SF), Contrast Focus Measure (CF), Gradient energy (GE), Histogram Entropy (HE), Gray level variance (GV), Sum of Coefficients the Wavelet (SW), Variance of Coefficients the Wavelet (VW). The proposed method has been accomplished on six pairs of multimodal images namely (Pair1, Pair2, Pair3, Pair4, Pair5, and Pair6) in form of (six visible images) and (six infrared images) in size of 256X256 as illustrated in Fig. 6. The datasets have been collected from the website (https://figshare.altmetric.com/details/2309122) under name TNO dataset. This study is performed by using MATLAB programming language version (9.0.2) under a windows 10 Pro environment.
Fig. 7. illustrate the resultant images from image fusion-based DWT, SWT, and the Proposed Method. (a) pair1 resultant image from fusion based-DWT, (b) pair1 resultant image from fusion-based SWT, (c) pair1 resultant image from fusion-based Proposed Method, (d) pair2 resultant image from fusion-based DWT, (e) pair2 resultant image from fusion-based SWT, (f) pair2 resultant image from fusion-based Proposed Method, (g) pair3 resultant image from fusion-based DWT, (h) pair3 resultant image from fusion-based SWT, (i) pair3 resultant image from fusion-based Proposed Method. (j) pair4 resultant image from fusion-based-DWT, (k) pair4 resultant image from fusion-based SWT, (l) pair4 resultant image from fusion-based Proposed Method, (m) pair5 resultant image from fusion-based DWT, (n) pair5 resultant image from fusion-based SWT, (o) pair5 resultant image from fusion-based Proposed Method, (p) pair6 resultant image from fusion-based DWT, (q) pair6 resultant image from fusion-based SWT, (r) pair6 resultant image from fusion-based Proposed Method.

Visible

Infrared

Fig. 6. Images in form of visible and infrared

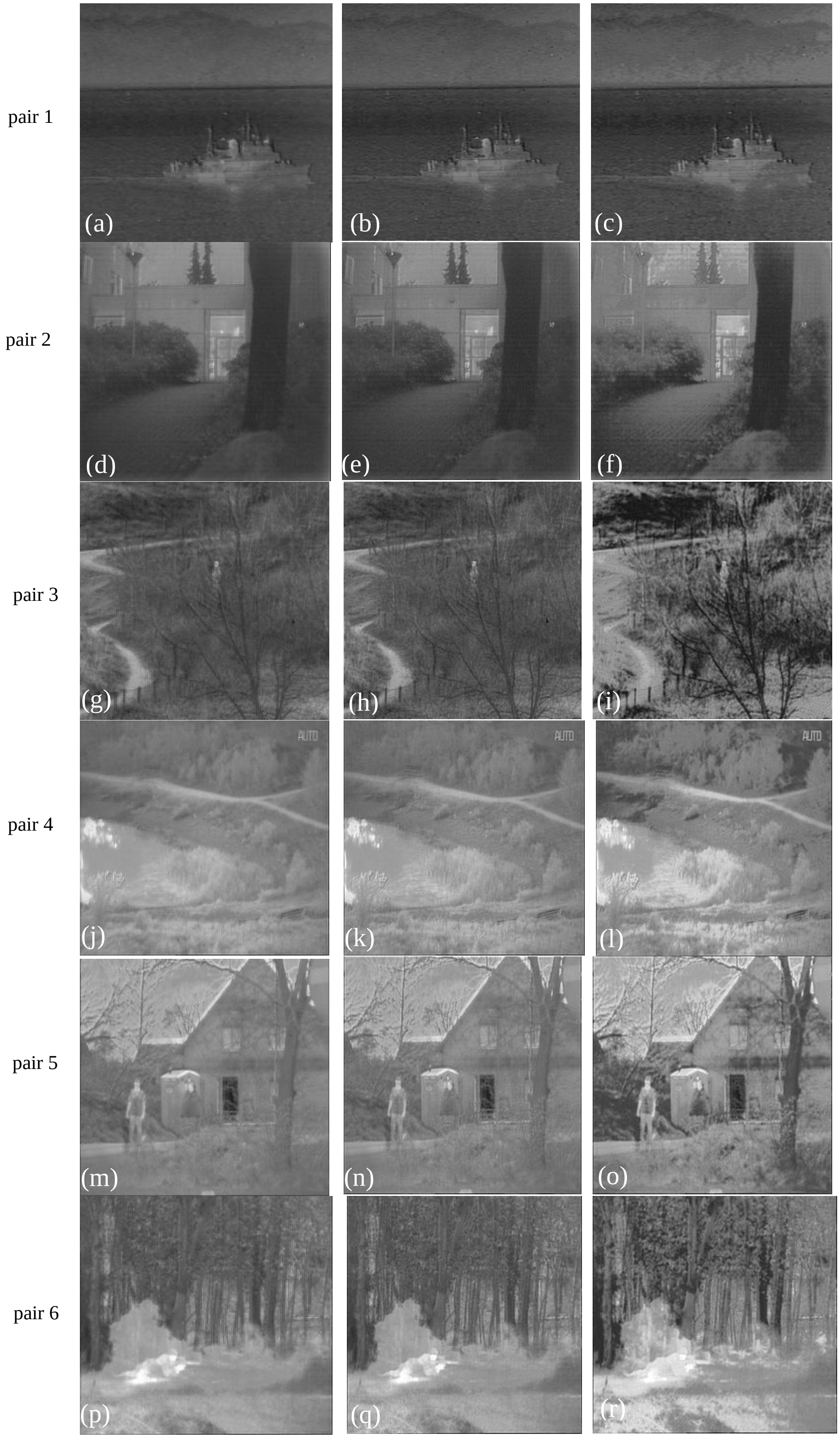

Fig. 7. resultant images from DWT, SWT, and Proposed Method based images fusion

Table 1. Performance metrics results for the DWT, SWT, and Proposed Method for image pair 1

Metrics\method	DWT	SWT	Proposed Method
SF	2.2576	3.0207	3.4751
CF	8.9052	16.4787	19.2500
GE	8.8625	23.8224	29.5369
HE	5.9256	5.9685	6.3083
GV	15.2200	15.5596	19.7916
SW	1.6681	1.6891	3.2380
VCW	1.3154	5.7845	6.6797

Table 2. Performance metrics results for the DWT, SWT, and Proposed Method for image pair 2

Metrics\method	DWT	SWT	Proposed Method
SF	1.9842	2.7133	3.5744
CF	11.3224	16.0521	20.8382
GE	10.9880	20.8160	31.3054
HE	6.5030	6.5056	6.9370
GV	29.3161	29.4503	30.6923
SW	1.8120	2.8692	3.4913
VW	3.7080	5.7862	6.3943

Table 3. Performance metrics results for the DWT, SWT, and Proposed Method for image pair 3

Metrics\method	DWT	SWT	Proposed Method
SF	3.7612	5.0523	7.2660
CF	20.4712	28.5233	49.5219
GE	32.2294	52.6199	94.2451
HE	6.1146	6.1567	7.1771
GV	18.7397	19.2418	37.2278
SW	3.4551	5.1932	7.8205
VW	5.7083	7.7096	14.0342

Table 4. Performance metrics results for the DWT, SWT, and Proposed Method for image pair 4

Metrics\method	DWT	SWT	Proposed Method
SF	1.9120	3.5700	4.4239
CF	11.1680	21.8396	27.7474
GE	10.8400	32.3038	44.8167
HE	6.5482	6.5782	7.0417
GV	24.2761	24.6866	34.0603
SW	1.6165	3.7960	4.5675
VW	5.2552	14.4551	17.1252

Table 5. Performance metrics results for the DWT, SWT, and Proposed Method for image pair 5

Metrics\method	DWT	SWT	Proposed Method
SF	2.2546	4.2911	5.5317
CF	13.3078	29.0514	39.5219
GE	15.4449	43.7570	63.9870
HE	6.4451	6.5136	7.1790
GV	23.4006	24.5813	36.2030
SW	1.8480	5.2522	6.5583
VW	4.6491	17.9211	20.1149

Table 6. Performance metrics results for the DWT, SWT, and Proposed Method for image pair 6

Metrics\method	DWT	SWT	Proposed Method
SF	2.7396	5.0480	6.0735
CF	15.6274	31.6507	40.7923
GE	19.6564	55.0912	73.3086
HE	6.9203	6.9654	7.4454
GV	34.3453	34.9075	44.0756
SW	2.2370	5.6901	6.8751
VW	6.6799	16.9797	20.3102

Based on experiment results, the proposed fusion method had best results than the traditional methods DWT and SWT. For instance, from table 1 for image pair 1, the value of histogram entropy for DWT is 5.9256 and for SWT is 5.9685, while for the proposed method is 6.3083. And from Table 2 for image pair 2, the value of the histogram entropy for DWT is 6.5030 and for SWT is 6.5056, while for the proposed method is 6.9370. The values obtained proved the effectiveness of the proposed method.

5. Conclusion

The objective of this paper is to enhance the visible-infrared image fusion based on stationary wavelet transform (SWT) and fuzzy histogram equalization (FHE). Although SWT-based image fusion has good representation for the fused image, the image resulting has low contrast and blur. This will affect the quality of the image information. In addition, the nature of the infrared images suffers from blurring which affects the quality of the fusion process. The proposed method is used to achieve a fused image with high-quality information by using FHE inside SWT based image fusion process. Images used in the experiment are gathered from different modalities such as visible image and infrared image and each of them provides different information. The experiment was evaluated using seven performance metrics, and the results obtained has been showing the efficiency of the proposed fusion method which exceeded the traditional methods DWT and SWT.

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