An Enhanced Image Fusion Framework Using Morphological Operations Based Unsharp Masking

[1] Sumanth Kumar Panguluri
Department of Electronics and Communication Engineering
Vignan's Foundation for Science, Technology, and Research
Vadlamudi, Guntur, Andhra Pradesh, 522213, India
skp6472@gmail.com

[2] Laavanya Mohan
Department of Electronics and Communication Engineering
Vignan's Foundation for Science, Technology, and Research
Vadlamudi, Guntur, Andhra Pradesh, 522213, India
laavanvijay@gmail.com

Abstract— **The idea of infrared (I-R) and Visible (V-I) image fusion is to integrate multiple source images and to produce a single useful informative image. Nowadays the image generated from I-R and V-I image fusion process has been used majorly in surveillance and remote sensing applications. It plays a crucial role in improving visibility and situation awareness especially in surveillance applications. This paper is introducing an enhanced I-R and V-I image fusion framework. A new Enhancement method is constructed using morphological operations based unsharp masking has been used in this algorithm for enhancing I-R and V-I source images. This enhancement method has produced high quality enhanced results which in return tremendously helped in improving the final fusion result. In this algorithm curve-let transform has been used to produce "detailed" and "approximation" coefficients. Integration of "approximation" coefficients is done through using "PCA fusion rule". Combining of "detailed" coefficients is done with using "max fusion rule". Fused image reconstruction is done with using inverse curve-let transform. The proposed fusion framework has produced superior results and outperformed than the similar existing fusion frameworks in terms of both visual quality and metrics values in comparison.**

Keywords- infrared image; visible image; morphological operations based unsharp masking; curve-let transform;

I. INTRODUCTION

I-R image is captured based on "thermal radiation of light". So, objects in the scene captured during adverse and low light weather conditions such as smoke, snow, fog and dust are clearly detected and properly seen in I-R image. The limitation of I-R image is that it provides "poor spatial resolution". So, that textures are completely eliminated in I-R image. Due to this humans are unable to extract clear view of scene information. On the other side V-I image is captured based on "reflection of light". So, objects in the scene captured during adverse and low light weather conditions are not properly seen or clearly detected in V-I image. But it provides "high spatial resolution". Due to that humans are able to extract complete view of scene information. Both I-R and V-I imaging functionalities are opposite and have their own advantage. So, combining both I-R and V-I images produce single comprehensive image [1]. It provides better object details and as well as excellent textures in individual image. The resultant image of I-R and V-I image fusion has been used mainly for surveillance in order to improve visibility and situation awareness.

Mostly fusion algorithms are classified into two types based on domain. They are

1. "Spatial-domain based fusion" algorithms
2. "Transform-domain based fusion" algorithms

In "spatial-domain based fusion" algorithms, source images are combined directly using fusion rules. No transforms are used in these algorithms. They are simple and easy to implement. Some of fusion rules used in these algorithms are PCA rule [2] and weighted average [3]. But major limitations of these algorithms are that results produced by them contains blur and are not visually clear in nature.

Whereas in "transform-domain based fusion" algorithms upon applying transform, source images are decomposed into multi-scale images. Later multi-scale images are fused by using fusion rules. Finally upon applying inverse transform produces resultant fused image. The advantages of these algorithms are that results produced by them are visually more perfect and closer to human vision. Mainly these algorithms are constructed using multi-scale transforms such as DWT [4], DTCWT [5], contour-let transform [6], and curve-let transform [7].

Apart from advantages the resultant images produced by these algorithms also has suffered with many problems such as unable to produce abundant information, description of edges are not clear, low contrast and important features of source images are not allowed into the fusion result. This paper is going to introduce an enhanced I-R and V-I image fusion framework using morphological operations based unsharp masking, curve-let transform and PCA in order to produce high quality I-R and V-I fused image by eliminating above-mentioned problems.

II. PROPOSED WORK

Block diagram of introduced algorithm has been shown in Fig. 1. First source images are resized to 256 × 256 images. Enhancement of resized source images is done with using morphological operations based unsharp masking. Later curve-let transform is applied on enhanced resized source images in order to produce "approximation" and "detailed coefficients" of both source images. "Approximation" coefficients of both source images are combined with the help "PCA fusion rule". Combining of "detailed" coefficients is done with using "max

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fusion rule". Reconstruction of resultant fused image is constructed with using inverse curve-let transform.

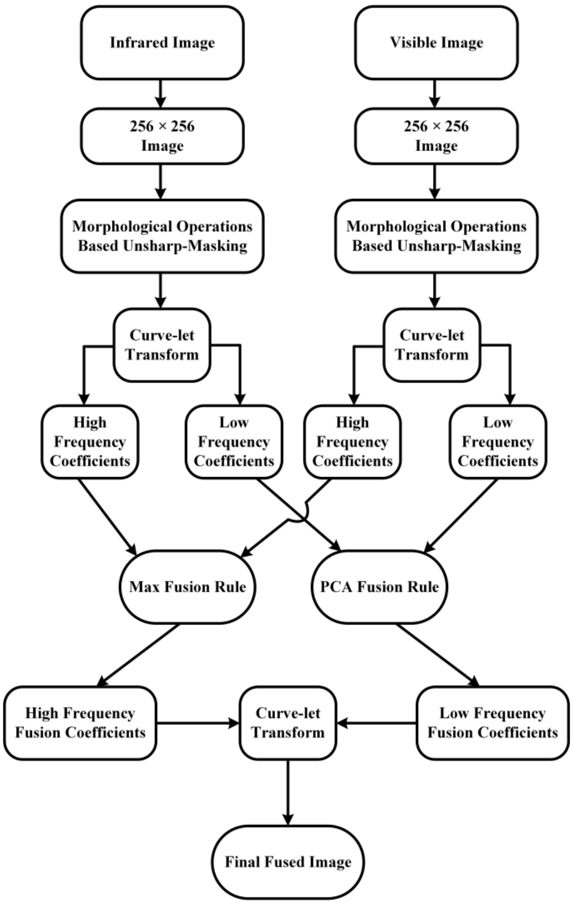

Fig. 1. The block diagram of proposed algorithm.

A. Morphological operations based unsharp masking

As shown in Fig. 1, Enhancement of resized source images is done with using morphological operations based unsharp masking.

Procedure for morphological operations based unsharp masking :

Step 1:

Take input image say it as f.

Step 2:

Apply morphological operation opening on f with using structuring element s. Let say it as g.

$$g = h \circ s \tag{1}$$

Step 3:

Apply morphological operation closing on g with using structuring element s. Let say it as h.

$$h = g \bullet s \tag{2}$$

Step 4:

h indicates blurred version of f. Now subtract opening result h from original image f. Let say it as f_S. Where f_S indicates sharpened image.

$$f_S = f - h \tag{3}$$

Step 5:

Add f_S with f. It gives final enhanced result. Let say it as E.

$$E = f + f_S \tag{4}$$

A new enhancement method that is constructed using morphological operations based unsharp masking has been used in this algorithm for enhancing edges of I-R and V-I source images. This enhancement method has produced high quality enhanced results which in return tremendously helped in improving the fusion result.

B. Curve-let Transform

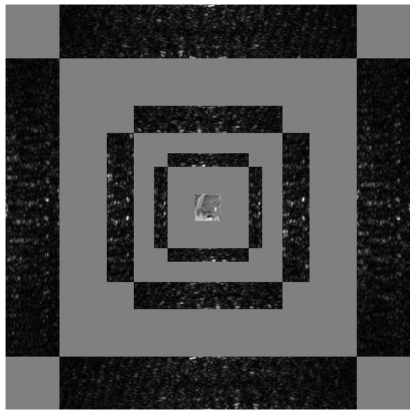

Fig. 2. "Approximation" and "detailed" coefficients produced on applying curve-let transform

Discrete curve-let transform is very efficient multi-scale directional transform for representing curve-like edges. The invention of curve-let transform is evolved from the concept of ridge-let transform [8]. Ridge-let transform is used for improving "straight-line singularities" in image. But the problem is that in real applications "straight-line singularities" are rarely present in image. Mostly curve singularities are present in image. For improving "local line or curve singularities" in image block ridge-let based transform [9] is introduced. This is later named as curve-let transform. The idea is to divide the image into sub-images and apply ridge-let transform on the obtained sub-images. This is so called as First generation curve-let transform. The limitation of first generation curve-let transform is that it uses unclear geometry of ridge-lets which results in performance degradation. Later second generation curve-let transform is proposed based on frequency partition concept. This is now treated as standard discrete curve-let transform which can used better for representing curve-like edges. In this algorithm second generation curve-let transform [10] has been used for decomposition of enhanced resized source images. Fig. 2

shows the “approximation” and “detailed” coefficients obtained on applying curve-let transform.

C. *Fusion of “Approximation” coefficients*

In this algorithm “approximation” coefficients of both source images are combined with using “PCA fusion rule”. The main principle of PCA is that “it converts set of possible correlated variables into a set of linearly uncorrelated variables”. It works in Eigen space. Let A_I represents “approximation” coefficients of enhanced resized I-R image and A_V represents “approximation” coefficients of enhanced resized V-I image.

The formula for “PCA fusion rule” is given by

$$F_{PCA} = P_1 A_I + P_2 A_V \tag{5}$$

Where P_1 and P_2 denotes first and second principal components.

The advantage of using “PCA fusion rule” in this algorithm is that “it allows more features of source images into final fused image”. So, that more information can be extracted from final fused image.

D. *Fusion of “Detailed” Coefficients*

In this algorithm “detailed” coefficients of both source images are fused with using “max fusion rule”. The formula for “max fusion rule” is given by

$$F_{Max} = \max\left(D_I, D_V\right) \tag{6}$$

Where D_I denotes “detailed” coefficients of enhanced resized I-R image and D_V denotes “detailed” coefficients of enhanced resized V-I image.

The use of “max fusion rule” in this algorithm helps in improving the edge information of final fused image.

III. Experimental Results and Analysis

A. *Source images used*

The source images that are used in this algorithm are taken from TNO image fusion dataset [11]. Three pairs of I-R and V-I images have been used for testing the performance of proposed method. They are shown in Fig. 3.

(a) (b) (c)

Fig. 3. Input images
(a) V-I and I-R images of “Forest image” (b) V-I and I-R images of “Sand-path image” (c) V-I and I-R images of “Garden image”

B. *Enhancement method results*

In this algorithm source images are enhanced by using morphological operations based unsharp masking.

The enhanced source images generated by using morphological operations based unsharp masking are shown in Fig. 4.

(a) (b) (c)

Fig. 4. Enhanced source images generated using morphological operations based unsharp masking
(a) Enhanced V-I and I-R images of “Forest image” (b) Enhanced V-I and I-R images of “Sand-path image” (c) Enhanced V-I and I-R images of “Garden image”

C. *Comparison methods*

In this paper proposed framework has been compared with four latest similar research methods. They are

1. DWT and Sharpen-filter based method [12]
2. PCA based Multi-modal method [13]
3. Curve-let multi-scale transform based method [14]
4. DWT and Unsharp masking based method [15]

All four methods have been implemented in MATLAB 2019b software on PC. PC configuration mainly includes 1Tera-byte ROM memory, Intel Core-i5 processor, 3.2 GHz speed and 4Giga-bytes RAM memory.

D. Visual comparison Analysis

Visual comparison analysis has been used for evaluating the performance of proposed method. Figs. 5-7 show fused results visual comparison for “Forest image”, “Sand-path image”, and “Garden image”. In Figs. 5-7, (a) represents “DWT and Sharpen filter based method fused image”, (b) represents “PCA based Multi-modal method fused image”, (c) represents “Curve-let multi-scale transform based method fused image”, (d) represents “DWT and Unsharp-masking based method fused image”, (e) represents “Proposed method resultant image”.

(a) (b) (c) (d) (e)

Fig. 5. Fused results visual comparison for “Forest image”
(a) DWT and Sharpen filter based framework resultant image (b) PCA based Multi-modal framework resultant image (c) Curve-let multi-scale transform based framework resultant image (d) DWT and Unsharp-masking based framework resultant image (e) Proposed framework resultant image

It clearly shows that the texture details such as edges are highlighted more in proposed framework resultant image as shown in Fig. 5(e) when compared to other framework resultant images shown in Figs. 5(a)-5(d). This clearly indicates that proposed framework has shown improved performance.

(a) (b) (c) (d) (e)

Fig. 6. Fused results visual comparison for “Sand-path image”
(a) DWT and Sharpen filter based framework resultant image (b) PCA based Multi-modal framework resultant image (c) Curve-let multi-scale transform based framework resultant image (d) DWT and Unsharp-masking based framework resultant image (e) Proposed framework resultant image

The person and sand-path details are clearly observed in Fig. 6(e) compared to other framework resultant images shown in Figs. 6(a)-6(d). This is mainly because proposed framework has produced high contrast.

(a) (b) (c) (d) (e)

Fig. 7. Fused results visual comparison for “Garden image”
(a) DWT and Sharpen filter based framework resultant image (b) PCA based Multi-modal framework resultant image (c) Curve-let multi-scale transform based framework resultant image (d) DWT and Unsharp-masking based framework resultant image (e) Proposed framework resultant image

The person, floor and door details are clearly observed in Fig. 7(e) compared to images shown in Figs. 7(a)-7(d). The main reason behind it is that the main features such as edges of source images are allowed more into the fusion result of proposed method.

E. Metrics values comparison Analysis

Metrics values comparison analysis has been used for measuring the performance of proposed framework. The metrics used are

a) Standard Deviation: Contrast details of image can be measured with using this metric [1].

b) Entropy: Total information of image can be calculated with using this metric [1].

c) Mean Gradient: Edge information of image can be measured by using this metric [1].

d) Spatial Frequency: Activity of image can be known with using this metric [1].

e) QAB/F: "Total edge transferred information from original input images to fused image" can be measured with using this metric [1].

The above mentioned metrics should be high for better quality images.

TABLE 1. FUSED RESULTS METRICS VALUES COMPARISON FOR "FOREST IMAGE"

Method	Metrics				
	Standard Deviation	***Entropy***	***Mean gradient***	***Spatial frequency***	***QAB/F***
Sharpen filter	33.6649	6.7825	17.5139	24.4235	0.3312
PCA	32.8658	6.5140	19.7061	23.4752	0.1847
Curve-let	27.3125	6.5592	11.1400	21.9834	0.3123
Unsharp masking	34.5629	6.7991	10.8214	24.2402	0.2864
Proposed	**38.9024**	**7.0202**	**20.8464**	**25.0072**	**0.4125**

TABLE 2. FUSED RESULTS METRICS VALUES COMPARISON FOR "SAND-PATH IMAGE"

Method	Metrics				
	Standard Deviation	***Entropy***	***Mean gradient***	***Spatial frequency***	***QAB/F***
Sharpen filter	29.1907	6.7659	20.1871	35.0034	0.3308
PCA	27.7295	6.4784	22.3358	38.9181	0.1494
Curve-let	24.6842	6.5383	16.1316	27.8812	0.4236
Unsharp masking	33.9778	6.9237	16.1049	31.2199	0.2533
Proposed	**43.6718**	**7.2956**	**24.6780**	**42.0860**	**0.4358**

TABLE 3. FUSED RESULTS METRICS VALUES COMPARISON FOR "GARDEN IMAGE"

Method	Metrics				
	Standard Deviation	***Entropy***	***Mean gradient***	***Spatial frequency***	***QAB/F***
Sharpen filter	42.3256	7.0933	18.4584	39.2649	0.4170
PCA	38.2889	6.6142	18.1349	42.7031	0.1979
Curve-let	35.9385	6.8591	10.3522	24.1552	0.4165
Unsharp masking	41.1372	6.9410	10.3008	26.3369	0.3275
Proposed	**47.7884**	**7.2342**	**18.8402**	**45.2584**	**0.4280**

Tables 1-3 show fused results metrics values comparison for "Forest image", "Sand-path image", and "Garden image". It clearly show from Tables 1-3, proposed method has got much better metric values when compared to other methods. These results clearly states that proposed framework fused image has achieved good brightness, high contrast, more information and rich textures when compared to similar existing method fused images.

IV. CONCLUSION

An enhanced I-R and V-I image fusion framework using morphological operations based unsharp masking has been proposed in this paper for producing high quality I-R and V-I fused image. A new enhancement method is constructed using morphological operations based unsharp masking has been used in this algorithm for enhancing I-R and V-I source images. An efficient multi-scale direction transform which is known as curve-let transform has been applied on enhanced resized source images in order to produce "approximation" and "detailed" coefficients of both source images. "Approximation" coefficients of both source images are combined with the help "PCA fusion rule". The advantage of using "PCA fusion rule" is that it allows more features of source images into fused image. Combining of "detailed" coefficients is done with using "max fusion rule". The purpose of using "max fusion rule" is to improve edges of fused image. Reconstruction of resultant fused image is constructed with using inverse curve-let transform. Three pairs of I-R and V-I images have been used for testing the performance of proposed framework. Proposed framework has been compared with four similar existing fusion frameworks. The proposed fusion framework has produced superior results and outperformed than the similar existing fusion frameworks in terms of both visual quality and metrics values in comparison.

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