A New Developed GIHS-BT-SFIM Fusion Method Based On Edge and Class Data

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ABSTRACT

The objective of image fusion (or sometimes pan sharpening) is to produce a single image containing the best aspects of the source images. Some desirable aspects are high spatial resolution and high spectral resolution. With the development of space borne imaging sensors, a unified image fusion approach suitable for all employed imaging sources becomes necessary. Among various image fusion methods, intensity-hue-saturation (IHS) and Brovey Transforms (BT) can quickly merge huge amounts of imagery. However they often face color distortion problems with fused images. The SFIM fusion is one of the most frequently employed approaches in practice to control the tradeoff between the spatial and spectral information. In addition it preserves more spectral information but suffer more spatial information loss. Its effectiveness is heavily depends on the filter design. In this work, two modifications were tested to improve the spectral quality of the images and also investigating class-based fusion results. First, a Generalized Intensity-Hue-Saturation (GIHS), Brovey Transform (BT) and smoothing-filter based intensity modulation (SFIM) approach was implemented. This kind of algorithm has shown computational advantages among other fusion methods like wavelet, and can be extended to different number of bands as in literature discussed. The used IHS-BT-SFIM algorithm incorporates IHS, IHS-BT, BT, BT-SFIM and SFIM methods by two adjustable parameters. Second, a method was proposed to plus edge information in previous GIHS_BT_SFIM and edge enhancement by panchromatic image. Adding panchromatic data to images had no much improvement. Third, an edge adaptive GIHS_BT_SFIM was proposed to enforce fidelity away from the edges. Using MS image off edges has shown spectral improvement in some fusion methods. Fourth, a class based fusion was tested, which tests different coefficients for each method due to its class. The best parameters for vegetated areas was k1=0.6, k2=0.8; and for urban region it was k1=0.4, k2=0.4. Results might be useful for future studies on fusion methods and their generalization.

1. INTRODUCTION

IN RECENT years, the number of spectral bands in a satellite image has increased significantly. Additionally, the spatial resolution of the image has also been enhanced. For remote sensing applications, the satellite images which can simultaneously offer high spatial and spectral resolutions are often required. It means that the ground and spectrum details must be accurately presented by a single image (Tu, 2012). The benefit of merged image has been demonstrated in many practical applications, especially for vegetation, land-use, precision farming, and urban studies (Tu, 2001). Due to this, various methods for image fusion have been described earlier (Amolins, 2007; Tu, 2001, 2004, 2005, 2012; Duo, 2007; Sh. Li, 2002; Z. Li,2005; Ling, 2007; Pajares, 2004; Yang, 2007; Rahmani, 2010; Chu, 2008). Among various image fusion methods, intensity-hue-saturation (IHS) and Brovey Transforms (BT) can quickly merge huge amounts of imagery and simultaneously preserving most of the spatial information provided that the color distortion is mitigated in the fusion; as they often face color distortion problems with fused images (Tu, 2005).

Furthermore, IHS-like and BT-like approaches are indeed efficient fusion methods since they require only arithmetical operations without any statistical analysis or filter design. The Smoothing-filter-based intensity modulation (SFIM) fusion is one of the most frequently employed approaches in practice to control the trade of between the spatial and spectral information. However, SFIM is not as efficient as BT-like and IHS-like methods in the fusion of high resolution images. In addition it preserves more spectral information but suffer more spatial information loss. Its effectiveness is heavily depends on the filter design (Tu, 2012). GIHS-BT-SFIM is an approach which was proposed by Tu et al. as an adjustable pan-sharpening approach for high resolution satellite imageries. This method has shown computational advantages among other fusion methods like wavelet, and could be extended to different number of bands. The introduced IHS-BT-SFIM algorithm incorporates IHS, IHS-BT, BT, BT-SFIM and SFIM methods by two adjustable parameters. On the other hand Rahmani et al. proposed an adaptive HIS Pan-sharpening method, whereby the edges of panchromatic image combine with the multispectral image to increase the spatial information as well as preserving the spectral quality. Another method is to incorporate edge information on GIHS_BT_SFIM fused image. An improvement is proposed in this study to combine previous approaches and test the results. Furthermore, a class-based image fusion method is introduced in this work to choose the best parameters for each class.

2. GIHS-BT-SFIM

2.1. Generalized Intensity-Hue-Saturation (GIHS)

In the HIS color space, intensity (I) is a measure of brightness, which is sometimes called luminance (L), Hue, (H) is the color, measured as the angle around a color wheel or color hexagon (Almoni, 2007), and Saturation is the amount of color, representing the orthogonal distance from intensity axis in the HIS color space (Gonzalez, 2002). Generalized IHS (GIHS) or Fast IHS (FIHS) is a unifying image fusion method in which the low resolution intensity component (I_0) in HIS space is replaced by a gray-level image with higher spatial resolution (I_{new} or pan) and transformed back to the original RGB space with the original H and S components (Tu, 2001).

$$\begin{bmatrix} R_{new} \\ G_{new} \\ B_{new} \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I_{new} \\ v1_0 \\ v2_0 \end{bmatrix} \quad (1)$$

To develop a computationally efficient method without the coordinate transformation, (1) can be rewritten as

$$\begin{bmatrix} R_{new} \\ G_{new} \\ B_{new} \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I_0 + (I_{new} - I_0) \\ v1_0 \\ v2_0 \end{bmatrix} = \begin{bmatrix} R_0 + \delta \\ G_0 + \delta \\ B_0 + \delta \end{bmatrix}$$
(2)

where $\delta = I_{new} - I_0$. So, the fused image $[R_{new}, G_{new}, B_{new}]^T$ can be easily obtained from the resized original image $[R_0, G_0, B_0]^T$, simply by addition. A merit of the method lies not only on its fast computing capability for fused images but also its ability to extend traditional three order transformations to arbitrary order. That is $F_i = M_i + \beta$, where M_i denotes the resized hyperspectral (HS) or multispectral (MS) image of band i, $\beta = Pan - I_0$,and $I_0 = ((1/l)\sum_{i=1}^{l} M_i)$, l represents the order or the number of bands (Tu, 2001). I_0 value can be computed as the band distances, their weighted (adjusted) average or simply their average same as the above mentioned, in WorldView-1(Tu, 2012). Using weighting coefficients on green and blue band (for IKONOS image) in an attempt to minimize the difference between I and panchromatic image, leads to spectral adjusted IHS (SA-IHS) method.

2.2. Brovey Transform (BT)

In contrast to the IHS method, the BT method is a ratio fusion technique that preserves the relative spectral contribution of each pixel, but replaces its overall brightness by the high-resolution panchromatic image (Tu, 2005). It is operated by

$$\begin{bmatrix} R_{BT} \\ G_{BT} \\ B_{BT} \end{bmatrix} = \frac{Pan}{I} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \gamma_{BT} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (3)$$

And I, is the intensity of resized MS or HS image calculated as the above.

2.3. Smoothing-Filter-Based Intensity Modulation (SFIM)

SFIM is a BT-like approach, uses a smooth version of pan image (P_L), in lieu of MS image intensity component as denominator of defined ratio (γ_{BT}). Thereupon, this method is defined by

$$\begin{bmatrix} R_{BT} \\ G_{BT} \\ B_{BT} \end{bmatrix} = \frac{Pan}{P_L} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (4)$$

where, P_L is often obtained from a 7×7 mean filter. It is known that the spatial resolution can be improved by increasing the mask size of the low-pass filter in the SFIM method (Tu, 2012).

2.4. An Adjustable GIHS-BT-SFIM

As it would be mentioned in the next part, IHS technique generates significant saturation compression, and the BT method suffers from saturation stretch. Motivated by this idea, an adjustable IHS-BT approach was used (Tu, 2005), then the SFIM method incorporates into the IHS-BT-SFIM approach (Tu, 2012) by the following equation.

$$\begin{bmatrix} R_{new} \\ G_{new} \\ B_{new} \end{bmatrix} = \frac{P}{I + k_1.(\hat{P} - I)} \begin{bmatrix} R + k_2.(\hat{P} - I) \\ G + k_2.(\hat{P} - I) \\ B + k_2.(\hat{P} - I) \end{bmatrix} \quad \hat{P} = P \text{ or } P_L \quad (5)$$

k_i is the module selection parameters and defined as to be $0 \le k_i \le 1$.

3. EDGE ADAPTIVE IHS

An Edge adaptive procedure was introduced by Rahmani et al. to enforce fidelity away from the edges. They have used an edge detecting function, h(x) in the IHS fusion method in the manner of

$$F_i = M_i + h(x)(P - I) \quad (6)$$

Where, F_i is the fused image and M_i is the band i of the MS image. In this case h(x) is equal to one on edges and equal to zero off edges. Edge adaptive method produces images with high spectral resolution while maintaining the high-quality spatial resolution of the original IHS.

4. EDGE ADAPTIVE GIHS-BT-SFIM

In many applications such as precision farming and urban classification, there's a need to have more precise information on edges because of the error occurrence is especially there. Using MS image data off edges and the minimum saturation on edges presents a good quality on spatial and spectral information for image based analysis purposes similar to classification. So, in this improved method edges are transferred from the GIHS-BT-SFIM image to the MS image. This approach extracts the edges from the pan-chromatic image; where there are edges the IHS-BT-SFIM product was imposed, otherwise, the MS image was used. In this case the fused multichannel image can be formed by the new formula,

$$I^{''} = \frac{P}{P + (I-P).h(x) + k1.h(x).\left(\hat{P}-I\right)}\left(I + k2.h(x).\left(\hat{P}-I\right)\right) \quad (7)$$

$$\hat{P} = P \text{ or } P_L$$

Another approach, which uses panchromatic image on edges and GIHS-BT-SFIM off edges, can be introduced as equation (8),

$$I^{''} = \frac{P}{I + k1.h(x).\left(\hat{P}-I\right)}\left(I + k2.h(x).\left(\hat{P}-I\right)\right) \quad (8)$$

$$\hat{P} = P \text{ or } P_L$$

The edges can be extracted using standard edge detection methods such as the canny detector (Canny, 1986). There is another edge detector suggested by Prona and Malik (1990) whereby the considerable results can be achieved in a fusion task which was introduced as the best in this study among other edge detectors in (Rahmani, et al. 2008),

$$h(x) = \exp(-\frac{\lambda}{|\nabla P|^4 + \varepsilon}) \quad ; \lambda = 10^{-9} \text{ and } \varepsilon = 10^{-10}$$

(9) The best edge detector in this study was Roberts, as experienced.

5. CLASS-BASED FUSION APPROACH

Because of different distortion extent due to each class, it was interesting to test every method in a class-based manner. This part was just tested on urban image because of more distinct nature of the classes and only two different types of objects defined as urban and vegetation cover. A class based fusion was tested, which gives different coefficients for each method due to its class. It means that, two adjustable parameters, introduced in first part for defining combination of fusion methods, has changed in a LUT form and their best values were selected according to the fusion results assessment in each class. There were 16 miscellaneous cases which were tested and acquainted in the following part.

6. RESULTS

Two datasets have been tested in this study. First one was a high resolution image in an urban area and the other a medium resolution image of an agricultural field. Setting k_i parameters of the GIHS-BT-SFIM, leads us to different fusion techniques and comparison for each method and their spectral and spatial quality was simply implemented. Spatial quality can be judged visually, but subtle color changes are more difficult to notice in this manner (Rahmani et al, 2010). In order to compare method results, spatial and spectral qualities by relying on both visual inspection and metric performance data were evaluated. Band-to-band correlation coefficient (CC), distortion extent, ERGAS, SAM, Q Index (Q-average), RMSE and RASE are the spectral metrics, and CC and average gradient are the spatial metrics for analyzing fusion methods fulfillment (Rahmani, 2008; Alparone, 2008; Zhang, 2008).

6.1. Urban area

The first study area is an urban region located in Shahriar, (Longitude: $51°3'$, latitude: $35°39'$) Tehran, Iran. The IKONOS image with four bands (Red, Green, Blue and Near infrared) and 3 meters spatial resolution in MS and one panchromatic band with 1 meter spatial resolution was used in this region (Figure 1). Results (Table 1) are

(Reference values)	Spatial (1)	CC - p(1)	Grad. (↑)	CC MS (1)	ERGAS (0)	QI (1)	RMSE (0)	RASE (0)	SAM (0)	SID (0)
IHS $\hat{P}=I$ $k1=k2=1$	0.9793949	0.9456128	31.578637	0.2226208	9.797232	0.9427865	145.56914	36.16468	2.041255	0.0038344
IHS-BT $\hat{P}=I$ $k1=k2=0.5$	**0.9800935**	**0.949865**	31.435052	0.2196149	9.7672105	0.927844	145.86261	36.237589	0.8914564	0.0016724
BT $\hat{P}=I$ $k1=k2=0$	0.9718691	0.9429588	31.560622	0.2215887	9.7863311	0.8959333	146.65628	36.434766	**2.29E-07**	0.0003077
BT-SFIM $\hat{P}=P_L$ $k1=k2=1$	0.9738466	0.9441899	31.591407	0.2209034	9.7911045	0.9313291	145.7741	36.215599	1.64E+00	0.003099
SFIM $\hat{P}=P_L$ $k1=1$ $k2=0$	0.8217719	0.4477592	38.038308	**0.8339869**	4.2892944	0.9745913	68.909097	**17.119531**	**2.29E-07**	0.0001111

Method										
Edge + IHS	0.680253	0.831546	40.24464	0.321928	8.846769	0.952452	133.9764	33.28463	1.692252	0.003682
Edge + IHS-BT (k=0.5)	0.680024	0.83469	40.16913	0.320423	8.821502	0.940162	134.2395	33.34998	0.749581	0.001413
Edge + BT	0.676058	0.828699	**40.2711**	0.321717	8.839665	0.913299	134.9936	33.53733	2.30E-07	0.000259
Edge + BT-SFIM	0.677401	0.830308	40.26946	0.320433	8.841822	0.941824	134.1846	33.33634	1.34E+00	0.002647
Edge + SFIM	0.782949	0.42262	37.34387	0.842689	4.142541	0.976479	66.69437	16.56931	**2.29E-07**	0.000112
Edge: HIS +MS	0.320391	0.214581	19.92138	0.936497	2.32683	**0.99688**	0.031071	9.26287	0.086614	0.001128
Edge: HIS_BT +MS	0.320256	0.214507	19.9217	0.93693	2.322272	0.996142	0.031121	9.277774	0.039367	0.000123
Edge: BT +MS	0.318512	0.214143	19.93042	0.936093	2.330462	0.994497	0.031357	9.348285	2.35E-07	1.66E-05
Edge: BT-SFIM +MS	0.319598	0.214311	19.9294	0.936637	2.325192	0.995262	0.031182	9.296099	0.050541	0.000182
Edge: SFIM +MS	0.354764	0.189779	18.9778	**0.964614**	**1.752521**	0.996388	**0.023563**	**7.024678**	2.35E-07	**0.000104**

Table 1: Assessing the fusion methods in an urban region

It is clear that edge adaptive method has improved spectral information in all procedures. Fusion results are provided in figure 1.
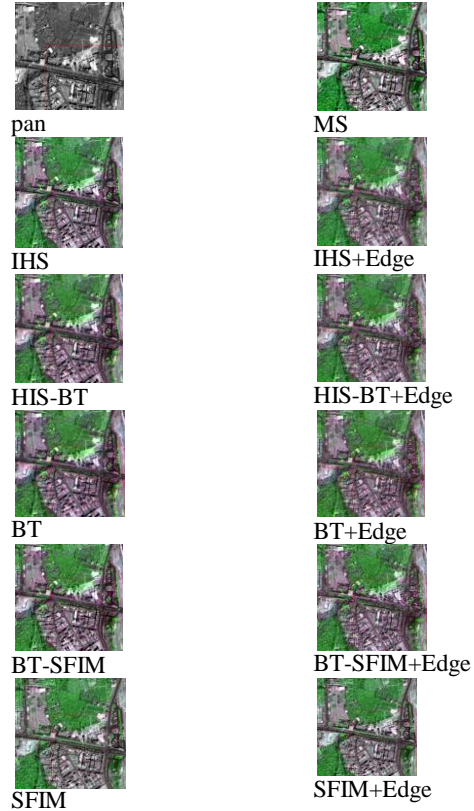

pan

MS

IHS

IHS+Edge

HIS-BT

HIS-BT+Edge

BT

BT+Edge

BT-SFIM

BT-SFIM+Edge

SFIM

SFIM+Edge

Figure 1:Results for Urban area

6.2. Agricultural fields

The area of interest deals with agricultural fields located around the village of Biddinghuizen in Flevoland, the Netherlands, which is characterized by the cultivation of arable crops (Abkar, 1994). This area represented a typical agricultural region in the Netherlands. The main crops are grass, potatoes, cereals, sugar-beets, beans, peas, and onions. The three spectral bands 3, 4, and 5 of the Landsat Thematic Mapper (TM) image that was acquired on 7 July 1987 has been used in this study. Results on this region are in (Table 2 and figure 2).

(Reference values)	Spatial (1)	CC- p(1)	Grad. (↑)	CC MS (1)	ERGAS (0)	QI (1)	RMSE (0)	RASE (0)	SAM (0)	SID (0)
IHS $\hat{P}=I$ $k1=k2=1$	0.97939495	0.945613	31.57864	0.222621	9.797232	0.942786	0.121308	36.16468	2.041255	0.003834
IHS-BT $\hat{P}=I$ $k1=k2=0.5$	**0.98000354**	0.949865	31.43505	0.219615	9.767211	0.927844	0.121552	36.23759	0.891456	0.001672

Method										
BT $\hat{P}=I$ $k1=k2=0$	0.97186908	0.942959	31.56062	0.221589	9.786331	0.895933	0.122214	36.43477	2.29E-07	0.000308
BT-SFIM $\hat{P}=P_L$ $k1=k2=1$	0.97384662	0.94419	31.59141	0.220903	9.791105	0.931329	0.121478	36.2156	1.63835	0.003099
SFIM $\hat{P}=P_L$ $k1=1$ $k2=0$	0.82177187	0.447759	38.03831	0.833987	**4.289294**	**0.974591**	0.057424	17.11953	**2.29E-07**	**0.000111**
Edge + IHS	0.9683169	0.946362	31.67542	0.220669	9.806361	0.918343	0.121483	36.21683	2.136681	0.004311
Edge + IHS-BT (k=0.5)	0.96946102	**0.950741**	31.5236	0.217567	9.779525	0.904138	0.121714	36.28582	1.034129	0.002236
Edge + BT	0.9579456	0.944735	31.67301	0.21895	9.797678	0.873873	0.122314	36.46473	0.18204	0.000969
Edge + BT-SFIM	0.96310779	0.945269	31.68285	0.219103	9.80137	0.908503	0.121625	36.25917	1.769849	0.003627
Edge + SFIM	0.76962972	0.469816	**38.85721**	0.809155	4.576026	0.95064	0.061239	18.25671	0.18204	0.000776
Edge: HIS +MS	0.310889	0.449469	8.16501	0.644215	11.32527	0.741658	0.04455	0.303412	0.597513	0.069668
Edge: HIS_ BT +MS	0.308092	0.446119	8.15694	0.64756	10.37553	0.740714	0.044889	0.305718	0.438284	0.008474
Edge: BT +MS	0.299276	0.435972	8.154986	0.670549	8.3003	0.737582	0.048911	0.33311	0.182216	0.00511

Method										
Edge: BT-SFIM +MS	0.303222	0.442026	8.203174	0.64545	10.2822	0.738535	0.045262	0.308258	0.534773	0.01595
Edge: SFIM +MS	0.401306	0.545576	6.006096	**0.899399**	3.383021	0.741403	**0.019747**	**0.13449**	0.182216	0.00511

Table 2: Assessing the fusion methods in an agricultural field

pan

MS

IHS

IHS+Edge

HIS-BT

HIS-BT+Edge

BT

BT+Edge

BT-SFIM
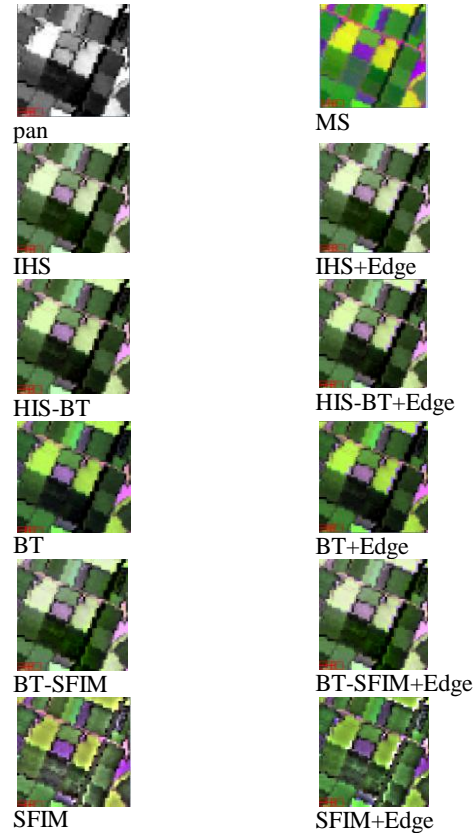

BT-SFIM+Edge

SFIM

SFIM+Edge

Figure 2: Results for Agricultural field

6.3. Class-Based Results (LUT-form)

In this part, just the outputs are presented for each group of modulation parameters. It is worth knowing that class part results are defined due to some ROIs for each class, because of the memory limitation for processing the whole image and it may have some effects on the last results. Look up table for these parameters are here (Table 3).

(Reference values) Class1: veg.	CC- p(I)-c1	CC MS (1)-c1	RMSE (0)-c1	CC- p(I)-c2 Class2: urban	CC MS (1)-c2	RMSE (0)-c2

K1=0.2 K2=0.2	0.938727	0.129064	4.065888	0.961073	0.142437	9.586439
K1=0.2 K2=0.4	0.945551	0.109794	5.10187	0.962885	0.129779	9.858437
K1=0.2 K2=0.6	0.927364	0.095161	6.298416	0.957006	0.118897	10.14125
K1=0.2 K2=0.8	0.905118	0.084486	7.579864	0.947262	0.109632	10.43399
K1=0.4 K2=0.2	0.892511	0.146586	3.351619	0.947313	0.156431	9.305324
K1=0.4 K2=0.4	0.947905	0.130391	4.008613	0.962375	0.143304	9.586911
K1=0.4 K2=0.6	0.953542	0.11549	4.863096	**0.963491**	0.131701	9.880744
K1=0.4 K2=0.8	0.940992	0.103565	5.828853	0.957035	0.121715	10.18576
K1=0.6 K2=0.4	0.793783	**0.155555**	2.99262	0.907764	**0.167822**	8.991131
K1=0.6 K2=0.6	0.91122	0.144887	3.365754	0.94813	0.155797	9.282394
K1=0.6 K2=0.8	0.953234	0.131253	3.973864	0.963114	0.144235	9.588235
K1=0.8 K2=0.2	**0.957978**	0.118663	4.727121	0.963485	0.133917	9.907305
K1=0.8 K2=0.4	0.821616	0.154609	**2.988708**	0.903145	0.16386	**8.939193**
K1=0.8 K2=0.6	0.920791	0.14442	3.375842	0.947669	0.154702	9.256606
K1=0.8 K2=0.8	0.956358	0.13196	3.952274	0.963256	0.145262	9.590602

Table 3: Class-based and modulation parameter effects on fusion results. c1; is for class one (vegetation cover) and c2; is for class2 (urban region).

7. CONCLUSION

In contrast with previous studies (Rahmani, 2010 & Tu, 2012), which only contemplate the spectral metrics in their work; there's a need to have both spatial and spectral metrics because of the fusion goal; in this study, different spatial and spectral metrics have been presented and considering all is obvious that adding edge information form panchromatic image into GIHS_BT_SFIM product has not much improvement in various processes (Eq.8). Using edge information on edges and MS data off edges has shown spectral enhanced fused images according to metrics in various methods (Eq.7). Nonetheless, there is some spatial information loss. So, it is preferable to choose the best method of fusion due to task aims and image data. BT method in both images offers the most balanced results among all according to both spectral and spatial information, and SFIM has the most spectral information. Moreover, some of edge detectors' performance was tested, and results show the high dependence of edge adaptive method on the edge detector used.

It is clear that, method sort (the modulation parameter) is important in image fusion process and the fusion results are affected by the class type. So, choosing the best modulation parameters (methods) in a fusion task should be considered. It is recommended to study on class based results more, in the future.

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