

Image Fusion

Chapter 6 –Optimize Image Fusion

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Chapter 6 - Optimize Image Fusion

像素级图像融合—

“Image fusion”+ “Optimize”

- 6.1 Image fusion analysis of color distortion based on IHS transform
- 6.2 Improved IHS fusion method-IIHS
- 6.3 Optimal fusion research based on characteristics and pixel United-UOF
- 6.4 Optimal Fusion Research Based on Fuzzy Integral-FOF



6.1 Image fusion analysis of color distortion based on IHS transform

Xiao Gang, Wang shu. Analysis of Color Distortion and Optimum Fusion for Remote Sensing Images Using the Statistical Property of Wavelet Decomposition. High technology letter, Vol12, No41.PP:397-402. Dec.2006. (EI: 070410388256).



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- Munseu提出了彩色系统格式，即用强度I、色度H和饱和度S来表示的（Intensity—Hue—Saturation）系统。强度I表示强度大小，色度H表示颜色纯度，而饱和度S表示具有相同亮度的颜色离开中性灰度的强度。
- IHS编码的优点是能把强度和颜色分开，因此，变换能够有效的将RGB系统中影像强度I与其光谱信息H、S相分离，这与人类对色彩感知参数有关。
- H、S和I相对而言，分辨率要求较低，这为在保持最多的信息下不同分辨率的遥感影像数据之间的融合提供了可能的途径。



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- IHS颜色模型有几种，模型不同，其变换的公式也不同，常用的有圆柱体、球体、三角形、单六棱锥等。

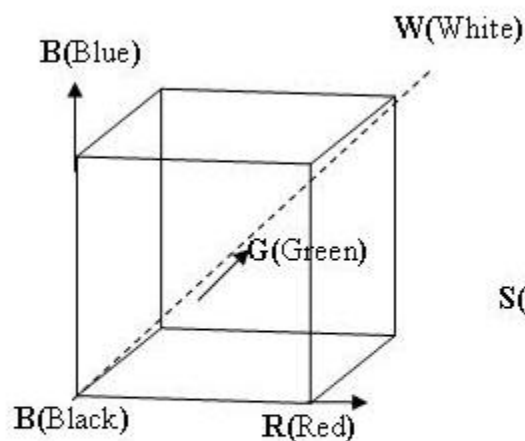


图6.2 RGB彩色立方体坐标系
Fig6.2 The Coordinate System of RGB Color Cube

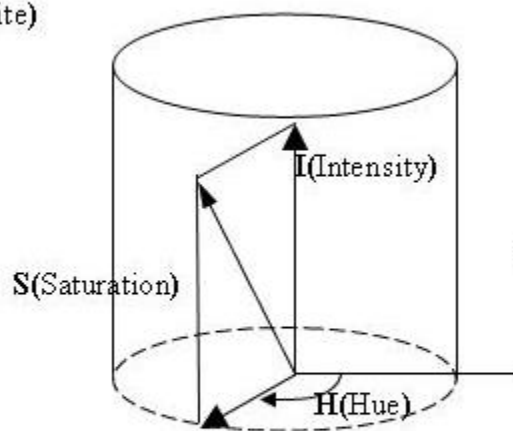


图6.3 IHS圆柱体彩色坐标系统
Fig6.3 The Coordinate System of IHS Color cylinder

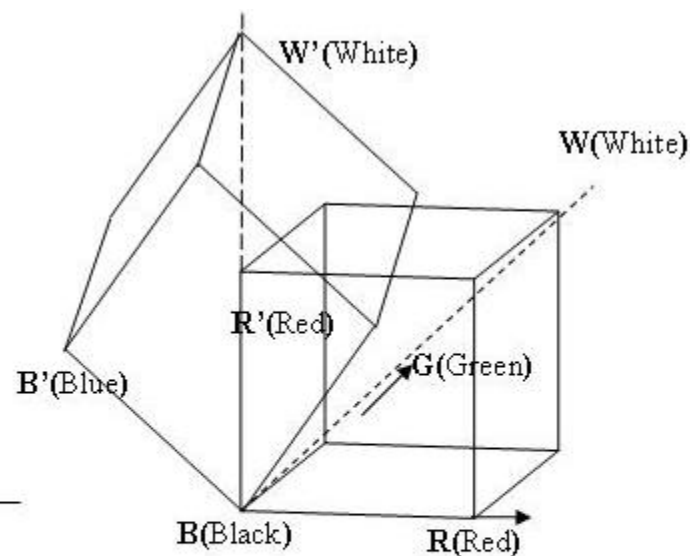


图6.4 RGB-IHS彩色空间变换
Fig6.4 The Transform from RGB to IHS Coordinate System

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- IHS变换融合—基本原理是用另一影像替代IHS三个分量中的某一分量，其中，强度分量I被替代最为常用

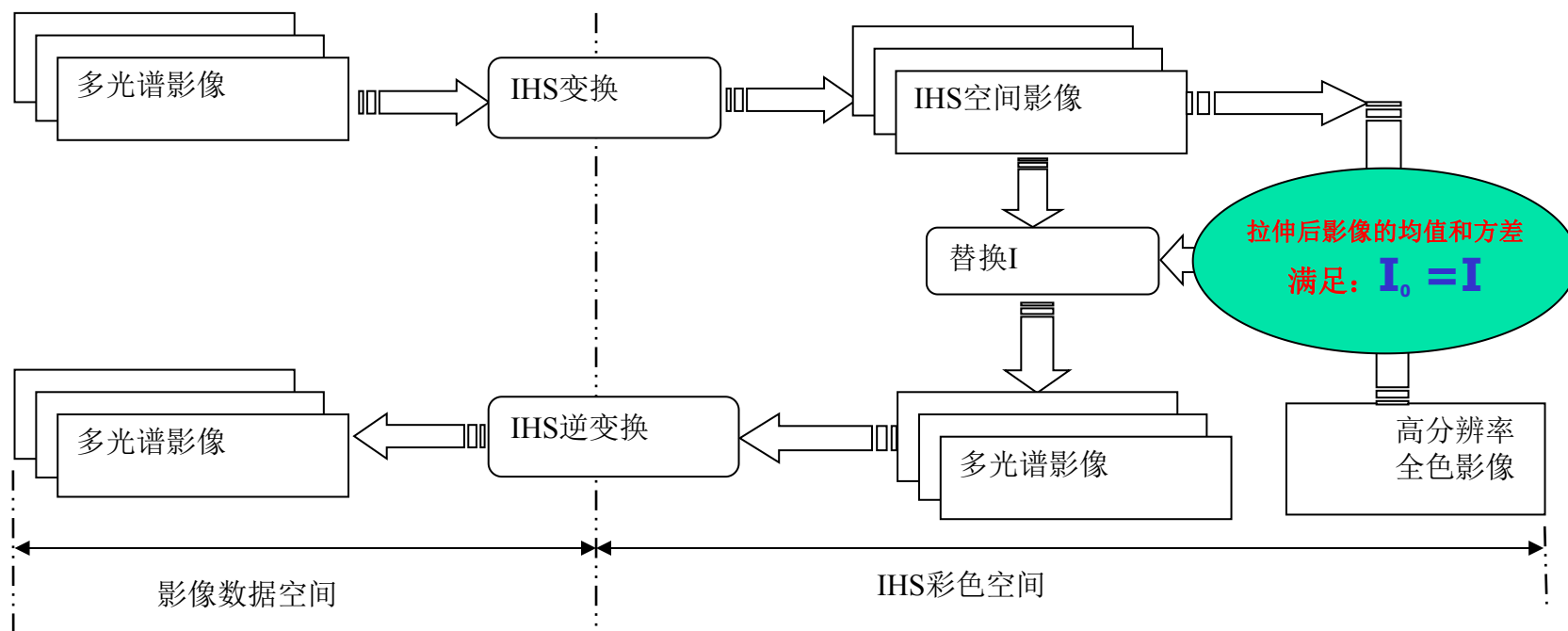


图6.1 彩色变换融合流程图

Fig.6.1 The Flowchart of IHS Color Fusion



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- **IHS变换融合优点**：使得融合后的影像既具有较高的空间分辨率（全色影像的分辨率信息），同时又保持了原低分辨率多光谱影像相同的**色度**和**饱和度**；
- **IHS变换融合缺点**：由于不同波段的数据具有不同的光谱特性曲线，**IHS**融合方法扭曲了原始的光谱特性，产生了不同程度的**光谱退化现象**或**彩色畸变**，因而不利于影像的正确识别和分类，特别是对于不同时相的多传感器遥感影像的影像融合，**IHS**融合方法无法使得融合影像的色调和原多光谱影像的色调保持一致，这种因融合而产生的光谱畸变，导致了影像用于地物识别和反演过程中误差增大。



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● 光谱退化现象或彩色畸变成因分析

● RGB彩色空间变换到IHS彩色空间的线性变换:

$$\begin{bmatrix} I \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \\ -\sqrt{2}/6 & -\sqrt{2}/6 & -\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$H = \tan^{-1}(v2 / v1), \quad S = \sqrt{v1^2 + v2^2}$$

线性逆变换:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \cdot \begin{bmatrix} I \\ v1 \\ v2 \end{bmatrix}$$

特点: 图像各饱和度分量**S**相对独立于强度分量**I**



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● 光谱退化现象或彩色畸变成因分析

- RGB彩色空间变换到IHS彩色空间的非线性变换（Fig6.4）：

$$I = (R + G + B) / \sqrt{3}$$

$$H = \begin{cases} \cos^{-1}(a) & \text{if } G \geq R \\ 2\pi - \cos^{-1}(a) & \text{if } G < R \end{cases} \quad a = \frac{(2B - G - R) / 2}{\sqrt{(B - G)^2 + (B - R)(G - R)}}$$

$$S = 1 - \frac{3 \min(R, G, B)}{R + G + B} = 1 - \frac{\sqrt{3}}{I} \min(R, G, B)$$

特点：图像饱和度分量S成比例与强度分量I



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光谱退化现象或彩色畸变成因分析

- A generalized IHS transformation can be written as follows

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

$$\sigma = I_{new} - I_0 \quad \longleftrightarrow \quad I_{new} = I_0 + \sigma$$

- 也即进行线性IHS彩色变换融合得到的RGB融合图像彩色立方体各分量 $R_{new}, G_{new}, B_{new}$ 为原始多（高）光谱图像对应各分量与的 σ 算术和。



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光谱退化现象或彩色畸变成因分析

- 原始的多光谱图像的饱和度分量 S_0

$$S_0 = 1 - \frac{3X_0}{R_0 + G_0 + B_0} = \frac{3I_0 - 3X_0}{R_0 + G_0 + B_0} = \frac{I_0 - X_0}{I_0}$$

融合图像的饱和度分量的值 S'

$$S' = 1 - \frac{3\min(R_0 + \sigma, G_0 + \sigma, B_0 + \sigma)}{R_0 + G_0 + B_0 + 3\sigma} = 1 - \frac{3(X_0 + \sigma)}{R_0 + G_0 + B_0 + 3\sigma} = \frac{I_0 - X_0}{I_{new}}$$

The difference between these two saturation values can be written as follows.

$$\Delta S = S' - S_0 = \left(\frac{I_0 - X_0}{I_{new}}\right) - \left(\frac{I_0 - X_0}{I_0}\right) = (X_0 - I_0) \frac{\sigma}{I_{new} \times I_0}$$

$$X_0 = \min\{R_0, G_0, B_0\}$$

σ 是导致彩色畸变的关键因素。由于在通常情况下有： $I_0 \neq I_{new}$ ，因此， $\sigma \neq 0$ ，因此，在通常情况，进行基于IHS彩色变换融合时，彩色畸变无法避免。



6.2 Improved IHS fusion method

IHS Arithmetic

Xiao Gang, Jing Zhongliang, Li Jianxun, Henry Leung. **Analysis of Color Distortion and Improvement for IHS Image Fusion.**
Proceedings of the 2003 IEEE International Conference on Intelligent Transportation Systems. Oct.12-15, 2003, Shanghai. PP: 80-85. (ISTP:BY24D).



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- A new intensity component can be adopted.

$$I'_{new} = (\alpha I_{new} + \beta I_0) / C$$

- A new fusion result can be re-calculated as follows

$$\begin{bmatrix} R1_{new} \\ G1_{new} \\ B1_{new} \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \cdot \begin{bmatrix} \frac{(I_{new} + I_0)}{2} \\ v1_0 \\ v2_0 \end{bmatrix} = \begin{bmatrix} R_0 + \frac{\sigma}{2} & G_0 + \frac{\sigma}{2} & B_0 + \frac{\sigma}{2} \end{bmatrix}^T$$

- the saturation value is changed when $I_0 \neq I_{new}$. The difference between these two saturation values is re-calculated as follows.

$$\Delta S_1 = S1' - S_0 = \left(\frac{I_0 - X_0}{I_{new} - \frac{\sigma}{2}} \right) - \left(\frac{I_0 - X_0}{I_0} \right) = (X_0 - I_0) \frac{\sigma}{(2I_{new} - \sigma) \times I_0} = (X_0 - I_0) \frac{\sigma}{(I_{new} + I_0) \times I_0}$$



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- Based on the first time iterated calculation, the I'_{new} can expressed as $I_i (i = 2, 3, \dots, n)$ and used to replace I_0 . I_2, I_3 are calculated as follows.

$$I_2 = \left[\frac{(I_{new} + I_0)}{2} + I_0 \right] / 2 = \frac{(I_{new} + 3I_0)}{4}$$

$$I_3 = \frac{\left[\frac{(I_{new} + I_0)}{2} + I_0 \right] / 2 + I_0}{2} = \frac{(I_{new} + 7I_0)}{8}$$

- The hue value of fused image is unchanged in this new fusion algorithm because the follow equation can be proven.

$$a3' = a2' = a1' = a' = a_0$$



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- The difference between these two saturation values is re-calculated as follows.

$$\Delta S_2 = S_2' - S_0 = \left(\frac{I_0 - X_0}{I_{new} - \frac{3\sigma}{4}} \right) - \left(\frac{I_0 - X_0}{I_0} \right) = (X_0 - I_0) \frac{\sigma}{(4I_{new} - 3\sigma) \times I_0} = (X_0 - I_0) \frac{\sigma}{(I_{new} + 3I_0) \times I_0}$$

$$\Delta S_3 = S_3' - S_0 = \left(\frac{I_0 - X_0}{I_{new} - \frac{7\sigma}{8}} \right) - \left(\frac{I_0 - X_0}{I_0} \right) = (X_0 - I_0) \frac{\sigma}{(8I_{new} - 7\sigma) \times I_0} = (X_0 - I_0) \frac{\sigma}{(I_{new} + 7I_0) \times I_0}$$

- As the analysis mentioned above, a conclusion is written as follows after iterated the arithmetical mean of I_{new} and I_0 to replace I_0 . Therefore, diminishing the saturation error can reduce the color distortion when the hue value unchanged in IHS color space.

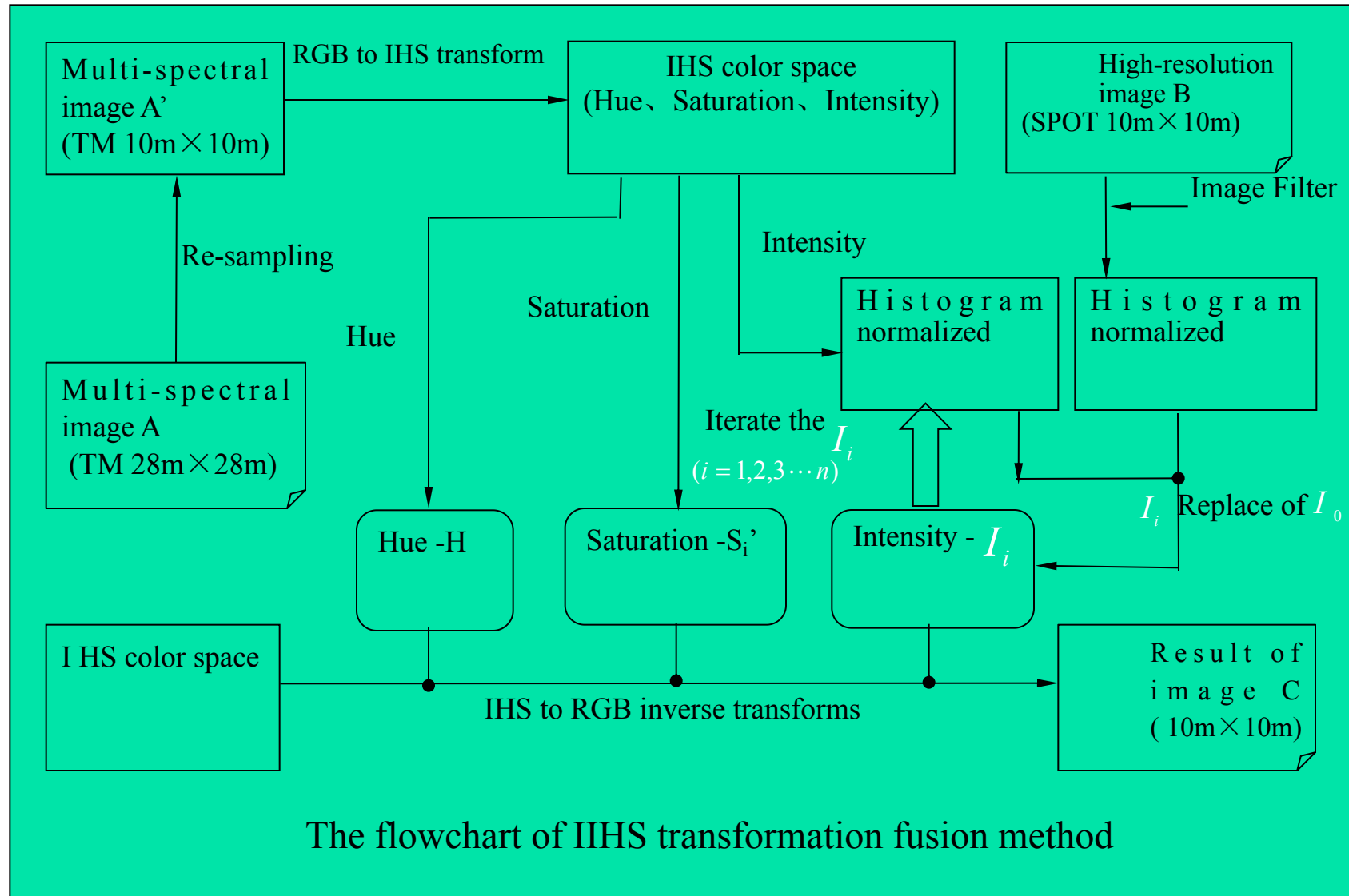
$$\Delta S_3 < \Delta S_2 < \Delta S_1 < \Delta S$$

- In the same way, the conclusion is listed as follows.

$$\Delta S_n < \dots < \Delta S_2 < \Delta S_1 < \Delta S$$



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IV. Experiments and quantitative evaluation



Fig2-1



Fig2-2



Fig2-3



Fig2-4



Fig2-5



Fig2-6



Fig2-7



Fig2-8

Fig.2-1 Resized TM image (10-m resolution).

Fig.2-2 Original SPOT image (10-m resolution).

Fig.2-3 Processed SPOT image with low-pass filter (10-m resolution).

Fig.2-4 The IHS fusion result without the adjustment of intensity component.

Fig.2-5 to Fig.2-8 The results of IIHS fusion method, which are corresponding to iterate I_0 one to four times.

Fig.2 The original SPOT and TM images and fused results

IV. Experiments and quantitative evaluation

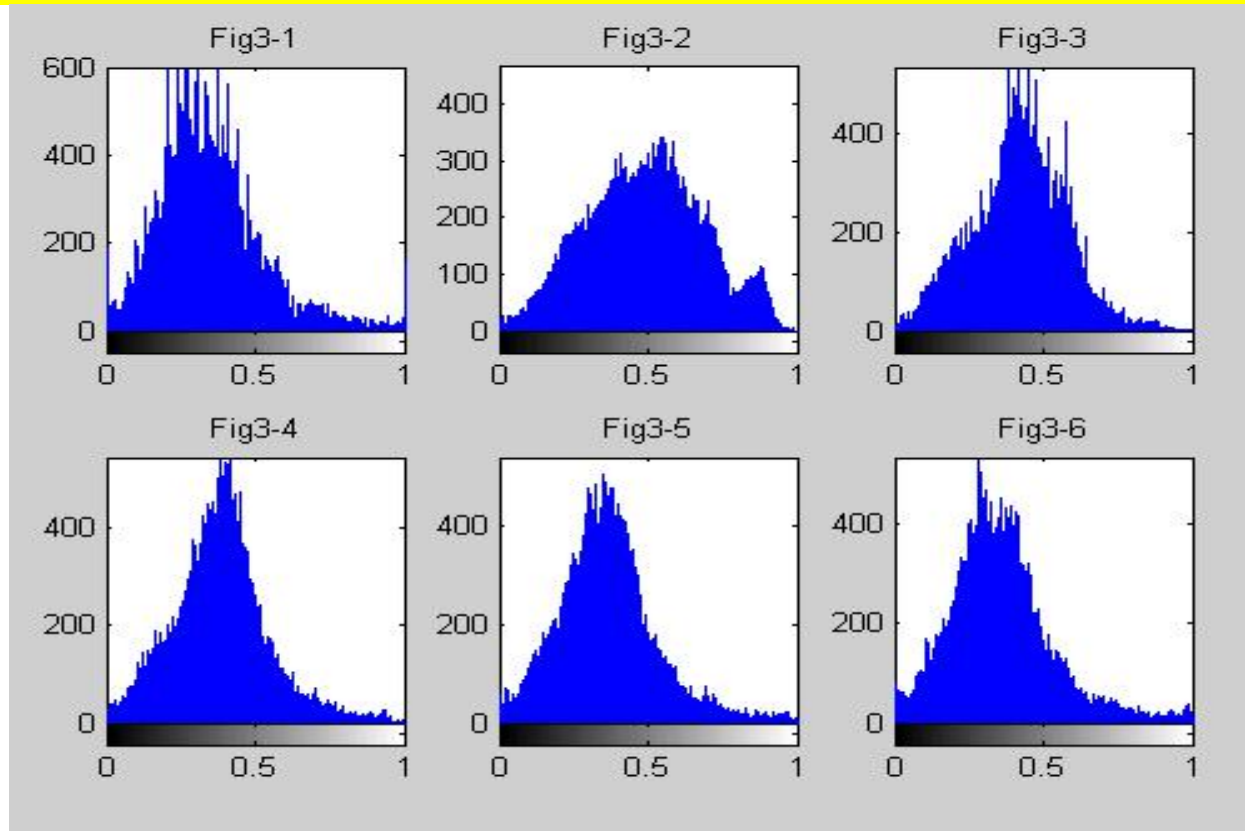


Fig.3-1 The histogram of . Fig.3-2 The histogram of .
 Fig.3-3 The histogram of the arithmetical mean of and
 Fig.3-4 to Fig.3-6 The histogram of (i = 2, 3, 4).
 Fig.3 The histogram of each intensity component

IV. Experiments and quantitative evaluation

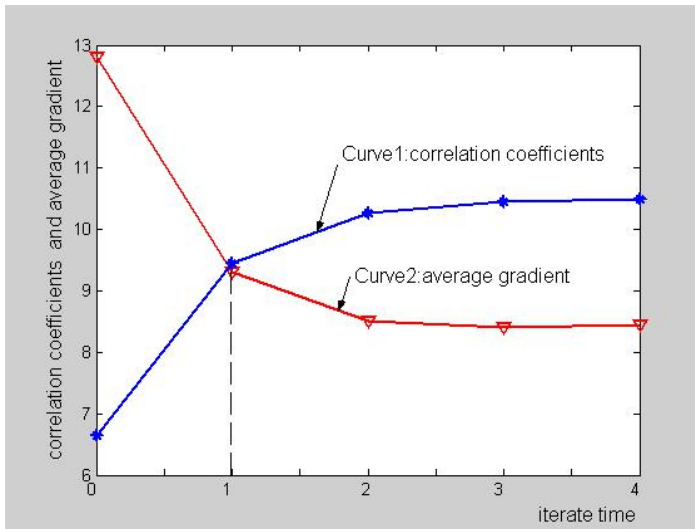


Fig.4 The comparing curves of correlation coefficients and average gradient (curve1: correlation coefficients; curve2: average gradient).

Table 1 The correlation coefficients between three-color (R, G, and B) resized Landsat TM images and fused images with IHS, IIHS methods, and their average values.

	R	G	B	Average
IHS	0.7457	0.4572	0.6966	0.6332
IIHS (I ₁)	0.9430	0.8308	0.9277	0.9005
IIHS (I ₂)	0.9875	0.9605	0.9839	0.9773
IIHS (I ₃)	0.9971	0.9909	0.9963	0.9947
IIHS (I ₄)	0.9993	0.9978	0.9991	0.9987

Table 2 The average gradient between three-color (R, G, and B) resized LANDSAT TM images and fused images with IHS, IIHS methods, and their average values.

	R	G	B	Average
IHS	12.4984	13.0444	12.8689	12.8039
IIHS (I ₁)	9.3938	8.9794	9.5659	9.3131
IIHS (I ₂)	8.6447	8.2210	8.6276	8.4978
IIHS (I ₃)	8.5435	8.2656	8.4031	8.4041
IIHS (I ₄)	8.5748	8.4101	8.3658	8.4505

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Conclusions

- The reason of color distortion problem arising in the process of IHS fusion is analyzed.
- A detailed study on IHS fusion indicates that it can modify the replaced intensity component to reduce the color distortion with IIHS method at the cost of the degradation of fused images' spatial resolution quality, i.e., the replaced intensity component is rectified by using proper weight coefficients I_{new} of I_0 and in IIHS method.
- Experiment with SPOT and TM remote sensing images demonstrates that this fusion method can improve the fused result with a viewpoint of synthetically quality evaluation. It is a practical and effective method for these two types of images.



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6.3 Optimal fusion research based on characteristics and pixel United-UOF

Xiao Gang, Jing Zhongliang, Li Jianxun, Henry Leung. **A UNITED OPTIMUM IMAGES FUSION BASED ON ANALYSIS OF COLOR DISTORTION.**
Chinese Optics Letters, Vol.2, No.3. P144~147.2004.4. (EI: 04278252257).



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● 基于象素和特征的联合最优融合研究

(UOF-United Optimal Fusion)

- 小波变换具有良好的分频特性，小波系数的统计特性反映了影像的边缘、线和区域等显著特征
- 在IHS空间，对强度分量I的高频部分利用多分辨率小波融合方法进行影像的高频细节特征融合，低频部分选取光谱信息和空间分辨率评价指标作为融合权系数求优指标，进行像素级最优融合
- 融合准则
 - 特征融合

$$W^k(2^j, x, y) = \begin{cases} W_A^k(2^j, x, y) & D_A^k > D_B^k \\ W_B^k(2^j, x, y) & D_A^k < D_B^k \end{cases}$$

- 像素融合

$$A(2^j, x, y) = k_1 A_A(2^j, x, y) + k_2 A_B(2^j, x, y)$$



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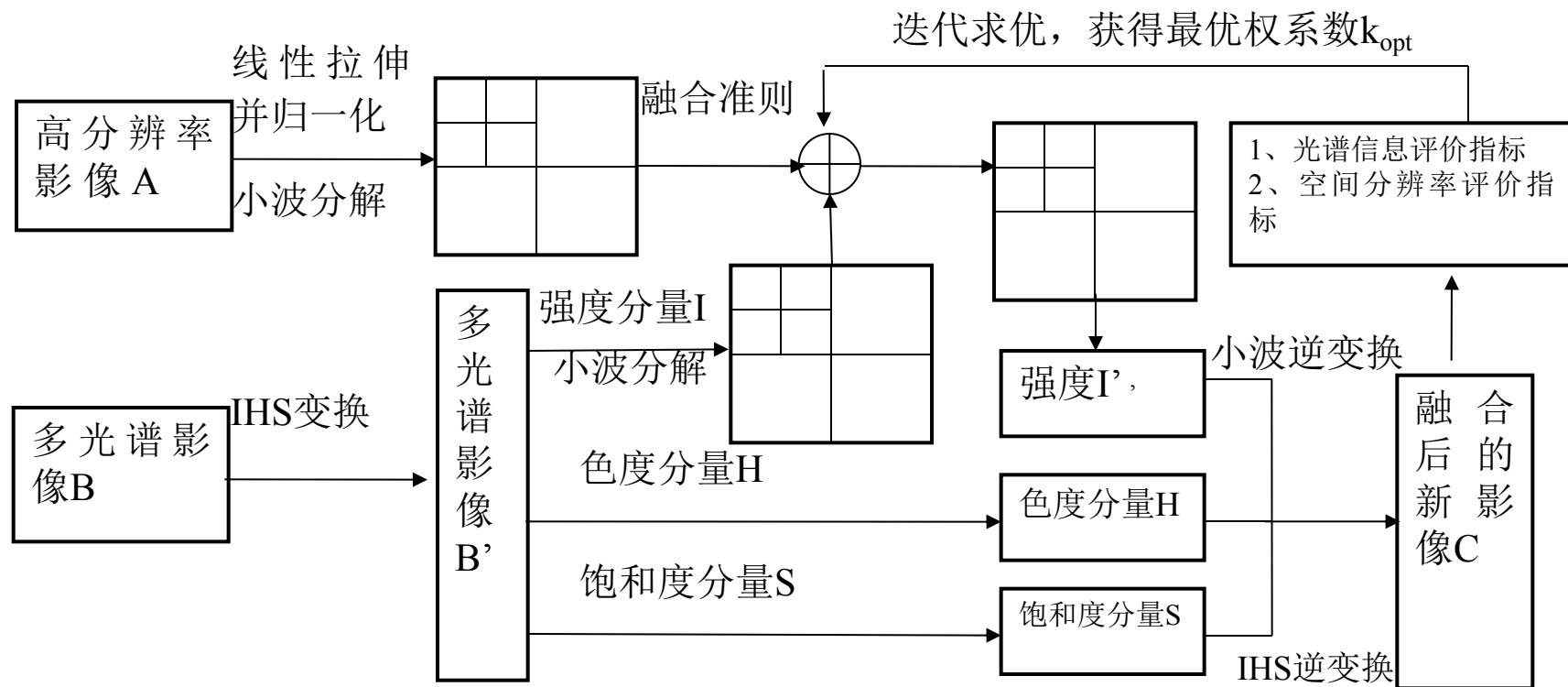


图3-7 基于小波统计特性的遥感图像像素与特征联合最优特征融合方法

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光谱信息评价指标:

$$E_{SP} = Corr(f, f_0) = \frac{\sum_{j=1}^{npix} (f_j - \bar{f})(f_{0j} - \bar{f}_0)}{\sqrt{\sum_{j=1}^{npix} (f_j - \bar{f})^2 \sum_{j=1}^{npix} (f_{0j} - \bar{f}_0)^2}}$$

空间分辨率评价指标:

$$E_{HF} = \frac{Corr(f^h, f_H^h) + Corr(f^v, f_H^v) + Corr(f^d, f_H^d)}{3}$$

平均梯度 (Average grads) 评价指标:

$$AG = \frac{1}{M * N} \sum_{i=1}^m \sum_{j=1}^n [\Delta x f(i, j)^2 + \Delta y f(i, j)^2]^{1/2}$$

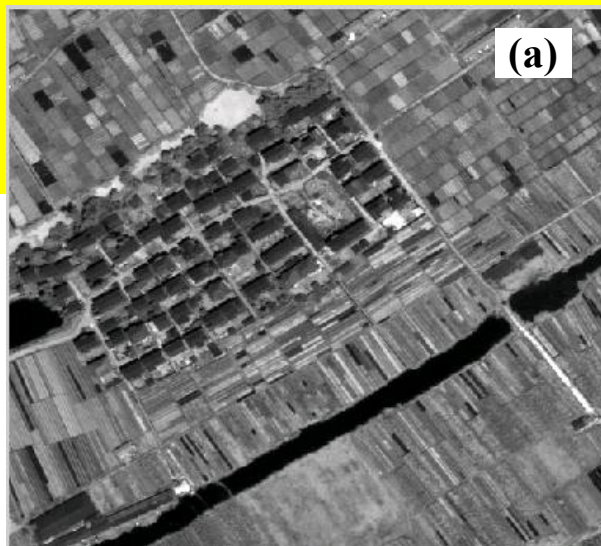
低频基带数据融合的权系数 k_{opt} 求优目标函数:

$$\begin{aligned} F(k_{opt}) &= F(k_1, k_2) = \text{Max}(E_{SP}(k_1, k_2); E_{HF}(k_1, k_2)); \text{Max}(E_{SP}(k_1, k_2); AG(k_1, k_2)) \\ &= \{E_{SP}(k_{opt}); E_{HF}(k_{opt})\} \text{OR} \{E_{SP}(k_{opt}); AG(k_{opt})\} \end{aligned}$$

$$D: g(k_{opt}): k_{opt} = k_1 = 1 - k_2; \quad k_{opt} \in D \in R \quad (0 \leq k_{opt} \leq 1)$$



(a) 高分辨率全色影像
(0.61m分辨率)



(b) 升采样后的多光谱遥感影像 (0.61m分辨率, 原为2.44 m分辨率)



(c) UOF融合方法得到融合图像(0.61m分辨率)

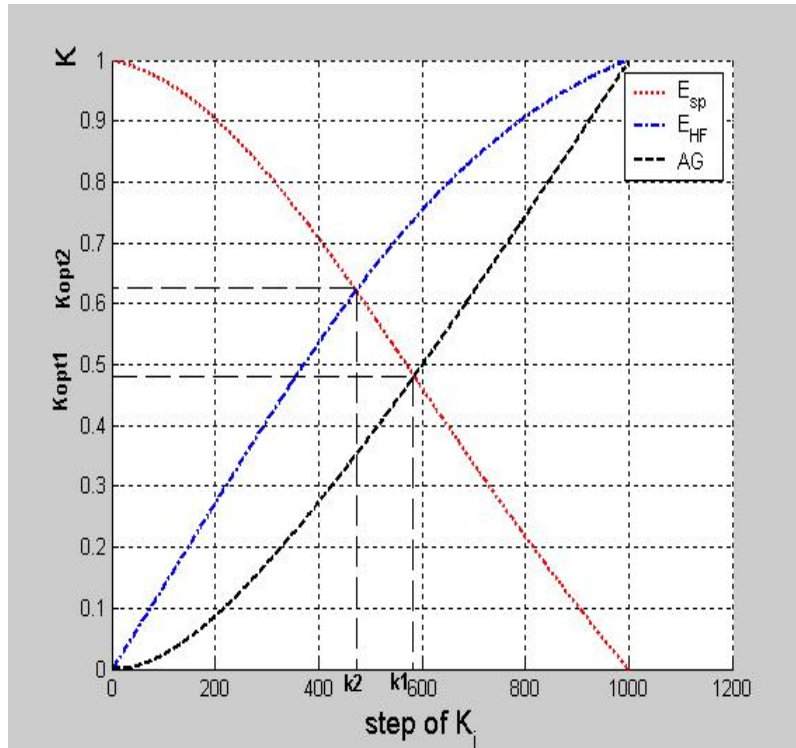


(d) IHS融合方法得到融合图像(0.61m分辨率)



原始遥感影像和融合结果 (Quick Bird)

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UOF评价指标曲线

融合结果的评价指标比较 (Quick Bird)

IHS	波段	相关系数		平均梯度	
	R G B	0.5624 0.4644 0.5060		10.6146 11.3663 9.5875	
UOF	k_i	$k_{opt1}=k_1=0.474; k_2=0.526$		$k_{opt1}=k_1=0.586; k_2=0.414$	
		相关系数	平均梯度	相关系数	平均梯度
	R	0.8488	8.9448	0.7950	9.0954
	G	0.7691	9.4102	0.6992	9.6055
	B	0.8247	7.9353	0.7626	8.1007

6.4 Optimal Fusion Research Based on Fuzzy Integral -FOF

Xiao Gang, Zhongliang JING, Shu Wang. Optimal Color Image Fusion Approach Based on Fuzzy Integral. Image Science Journal, Vol. 55, 2007, PP: 189-196. (SCI: 246HW).



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● 基于模糊积分的最优融合研究

(FOF-Fuzzy Optimal Fusion)

-UOF 算法的简化

求优目标函数:

$$F(k_{opt}) = \text{Max}\{E_{SP}(k_{opt}), E_{HF}(k_{opt})\}$$

$$\text{Domain: } g(k_{opt}) : 0 \leq k_{opt} \leq 1 \quad k_{opt} \in D \in R$$

一模糊积分及其综合单因素指标的应用

$$S = \int_A e(x) \circ g(x) = \sup_{\alpha \in [0,1]} \min[\alpha, g(A \cap E_\alpha)]$$

$$= \max_{\alpha \in [0,1]} [\min(\alpha, g(A \cap E_\alpha))]$$

$$\int_X e(x) \circ g(x) = \sup_{\alpha \in [0,1]} \min[\alpha, g(X \cap E_\alpha)] = \max_{\alpha \in [0,1]} [\min(\alpha, g(E_\alpha))]$$

$$S = \sup \{ \min[e(u_1), g(E_1)], \min[e(u_2), g(E_2)] \}$$



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一 基于模糊积分的最优融合

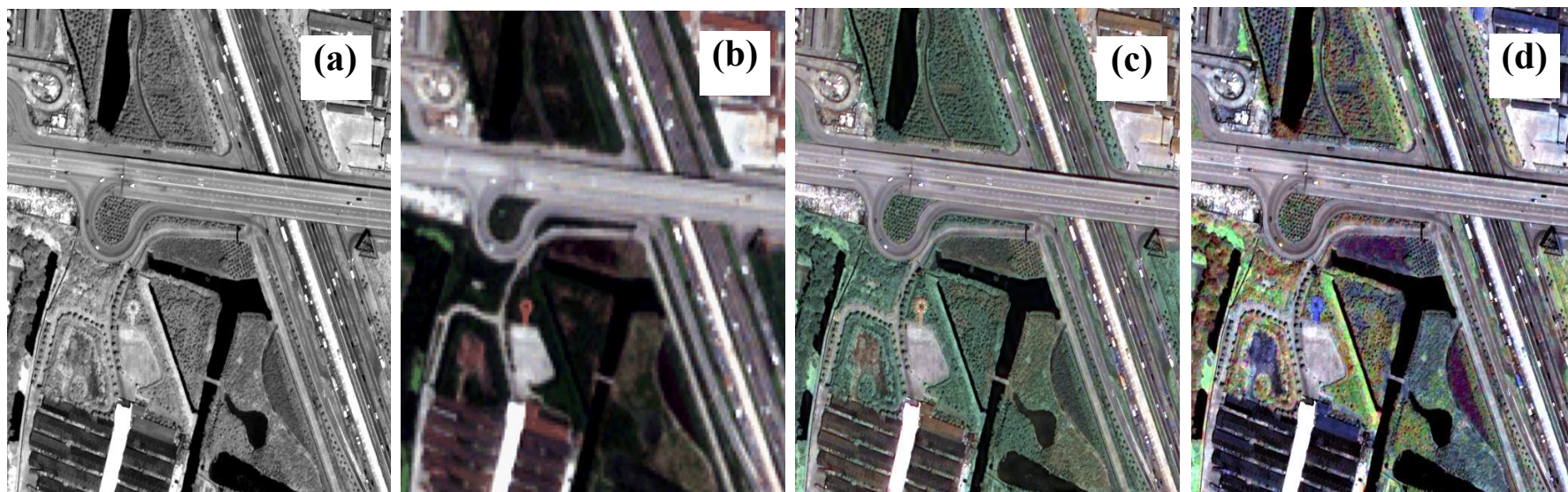
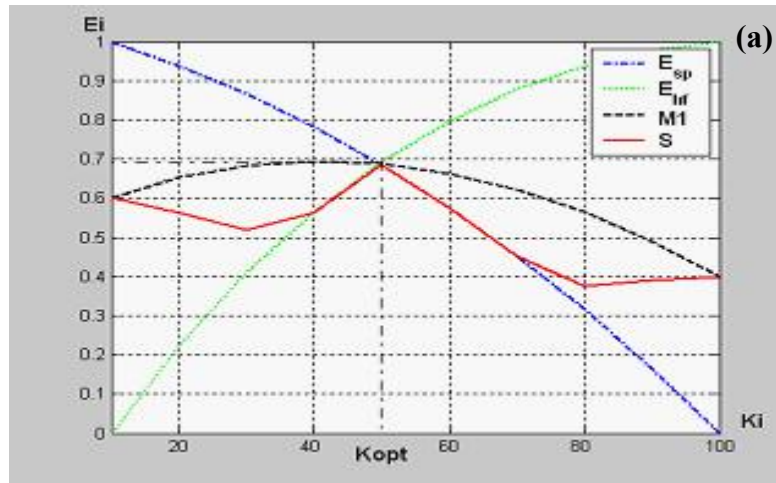


图3-11 原始卫星遥感影像及融合图像

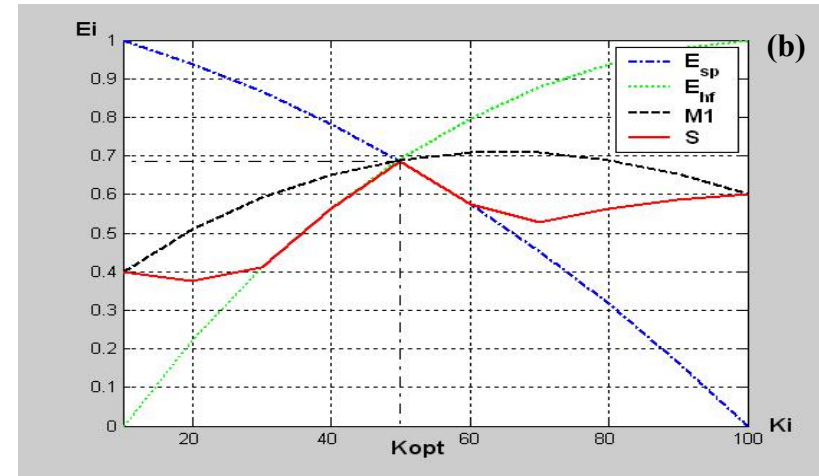
(a)高分辨率全色影像(0.61m分辨率) (b) 升采样后的多光谱遥感影像 (0.61m分辨率,原为2.44 m分辨率) (c)FOF融合方法得到融合图像 (d) IHS融合方法得到融合图像

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— 基于模糊积分的最优融合(续)



(a) 重视度: $g_1 = 0.6, g_2 = 0.4$



(b) 重视度: $g_1 = 0.4, g_2 = 0.6$

评价指标曲线

融合图像性能评价

	Band	Fig.3-11		Fig.3-12	
		CORR	AG	CORR	AG
IHS	R	0.5624	10.6146	0.4214	17.5486
	G	0.4644	11.3663	0.5112	16.4781
	B	0.5060	9.5875	0.5124	14.8623
FOF	R	0.8488	8.9448	0.7878	16.9718
	G	0.7691	9.4102	0.8040	15.3258
	B	0.8247	7.9353	0.7986	14.0322



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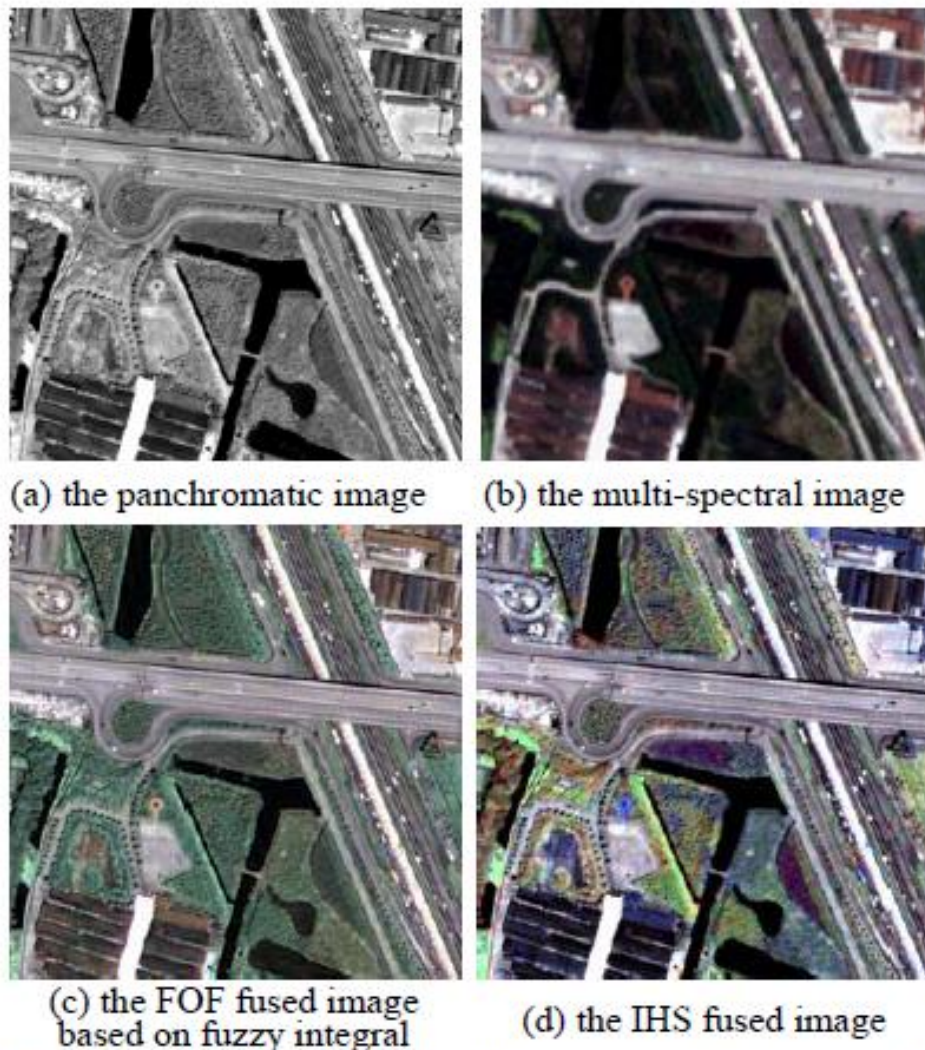


Fig.3 The original Quickbird satellite image and the fused results

Fig. (3) is a part satellite remote sensing data, obtained by Quick Bird satellite, Jun.2002. These images all show the highway and buildings of urban city, shanghai, China.

The Fig.3 (a) is a panchromatic image with 0.61-m spatial resolution. The original images multi-spectral image is 2.44-meter spatial resolution. It is re-sampled with 4 time ratios. The result is 512×512 pixels, showing as Fig.3(b). They are registered each other. The fused result with classical IHS method is shown as Fig.3 (d).

Tab.1 The Compare evaluation indexes for fused images (I)

	STEP	E_{SP}	E_{HF}	F	M_1
Fig3. (c)	K_1	0.96926	0.91429	0.60000	0.60000
	K_2	0.96851	0.91486	0.56304	0.65205
	K_3	0.96763	0.91534	0.51936	0.68317
	K_4	0.96660	0.91574	0.56355	0.69408
	K_5	0.96542	0.91607	0.68435	0.68725
	K_6	0.96409	0.91634	0.57494	0.66343
	K_7	0.96260	0.91655	0.45228	0.62257
	K_8	0.96094	0.9167	0.37516	0.56470
	K_9	0.95911	0.91681	0.39165	0.49080
	K_{10}	0.95710	0.91686	0.40000	0.40000
Fig3. (d)	K_1	0.96926	0.91429	0.40000	0.40000
	K_2	0.96851	0.91486	0.37536	0.50887
	K_3	0.96763	0.91534	0.40952	0.59196
	K_4	0.96660	0.91574	0.56355	0.65057
	K_5	0.96542	0.91607	0.68435	0.68871
	K_6	0.96409	0.91634	0.57494	0.70768
	K_7	0.96260	0.91655	0.52681	0.70772
	K_8	0.96094	0.91670	0.56274	0.68910
	K_9	0.95911	0.91681	0.58747	0.65357
	K_{10}	0.95710	0.91686	0.60000	0.60000

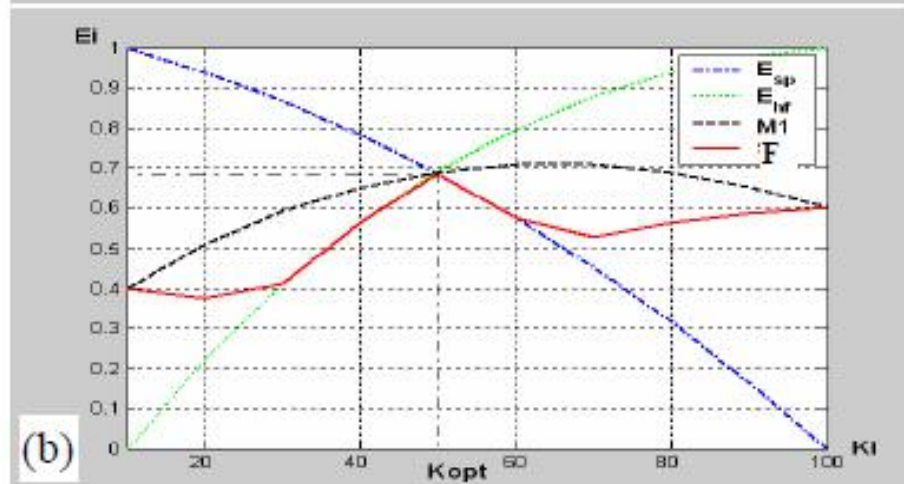
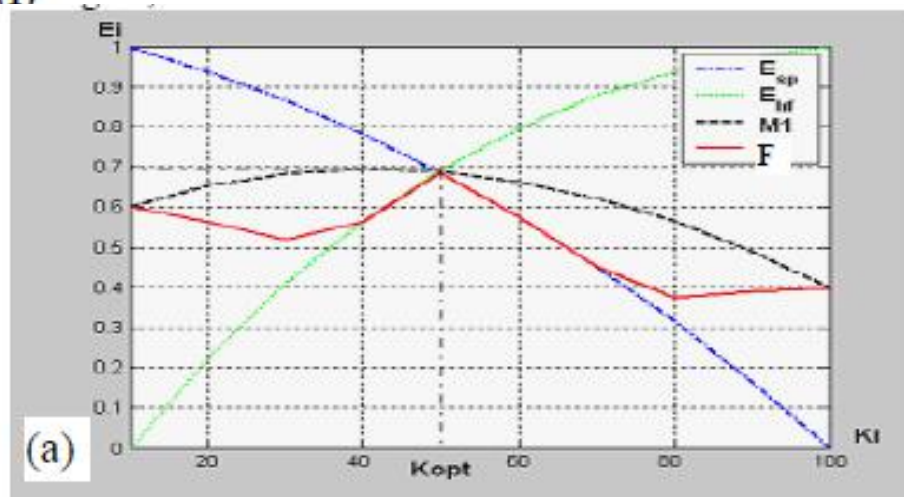
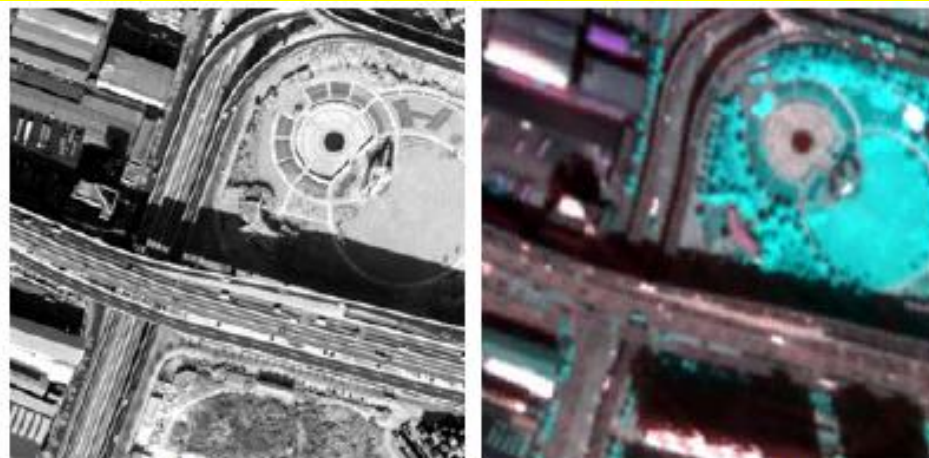
(a) $g_1 = 0.6, g_2 = 0.4$ (b) $g_1 = 0.4, g_2 = 0.6$

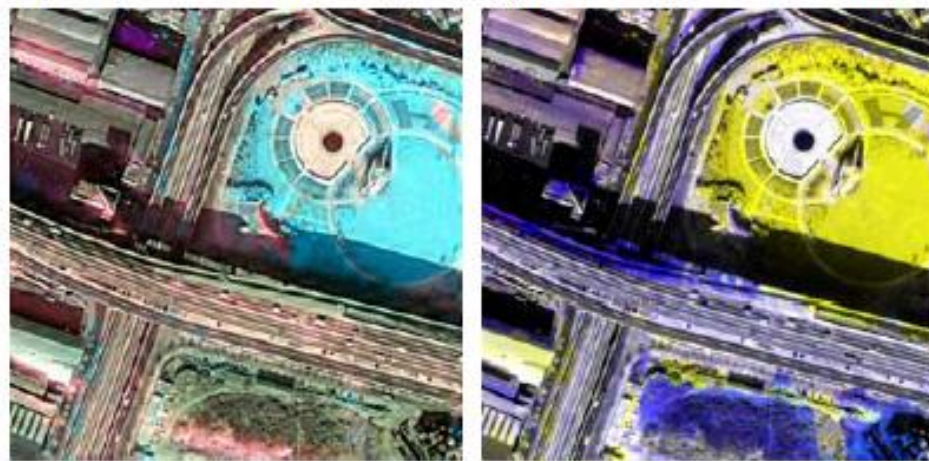
Fig.2 The evaluation indexes curves

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(a) the panchromatic image

(b) the multi-spectral HIS image



(c) the FOF fused image
based on fuzzy integral

(d) the IHS fused image

Fig.5 The original aerial remote sensing image and the fused results

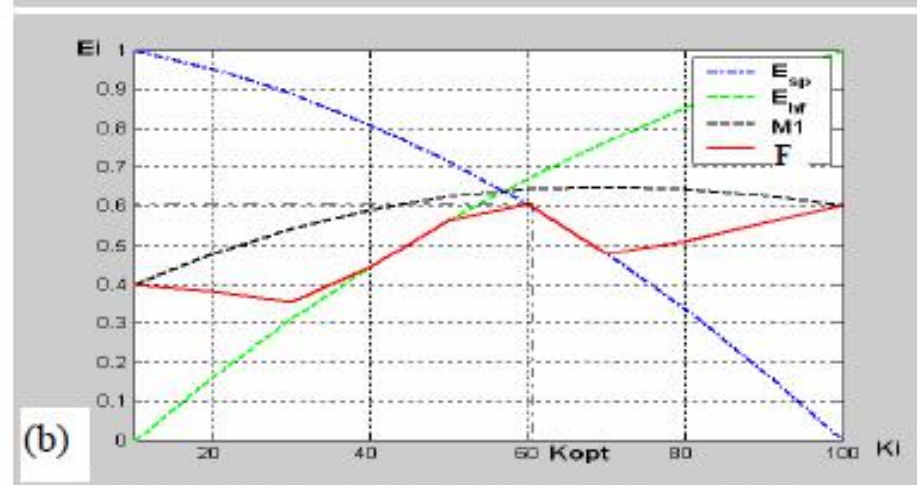
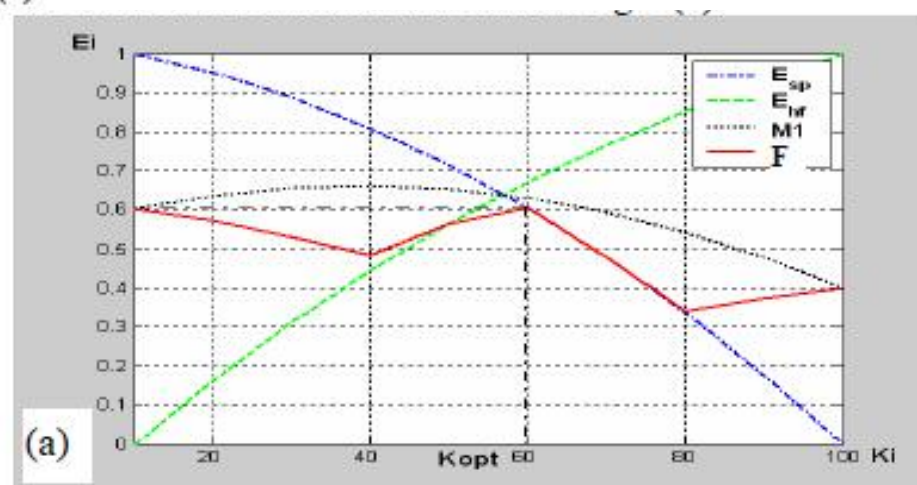
Fig. (5) is an aerial remote sensing data, which were obtained by HIS/CCD camera. These images all show the highway and buildings of urban city, shanghai, China. The Fig.5(a) is a panchromatic image with 0.42-m spatial resolution, 512×512 pixels, which was taken by 6000 pixels CCD camera at Oct, 2003. The multi-spectral image is 2.52-meter spatial resolution. It is re-sampled with 6 time ratios. These two cameras were installed on a same PAV30 platform. They are registered each other. The fused result with classical IHS method is shown as Fig.5 (d).



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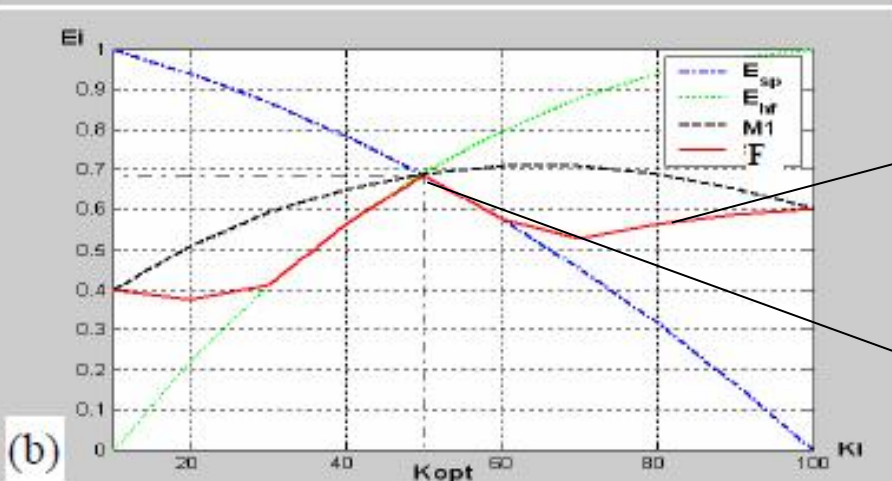
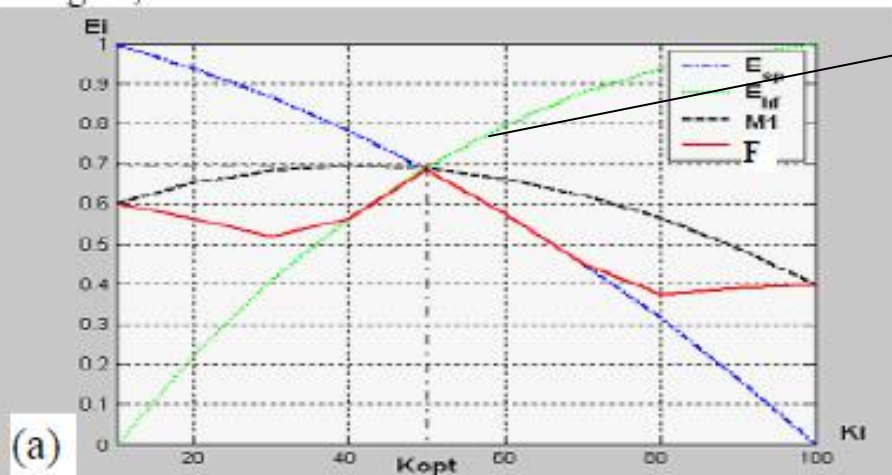
Tab.2 The Compare evaluation indexes for fused images (2)

Fig5. (c)	STEP	E_{SP}	E_{HF}	F	M_1
	K_1	0.95137	0.90349	0.60000	0.60000
	K_2	0.95020	0.90522	0.57033	0.63568
	K_3	0.94870	0.90678	0.53199	0.65653
	K_4	0.94685	0.90818	0.48483	0.66250
	K_5	0.94464	0.90944	0.56423	0.65419
	K_6	0.94207	0.91056	0.60450	0.63093
	K_7	0.93911	0.91156	0.47872	0.59351
	K_8	0.93576	0.91247	0.34053	0.54233
	K_9	0.93201	0.91329	0.37166	0.47777
	K_{10}	0.92785	0.91403	0.40000	0.40000
Fig5. (d)	STEP	E_{SP}	E_{HF}	F	M_1
	K_1	0.95137	0.90349	0.40000	0.40000
	K_2	0.95020	0.90522	0.38022	0.47826
	K_3	0.94870	0.90678	0.35466	0.54146
	K_4	0.94685	0.90818	0.44417	0.58972
	K_5	0.94464	0.90944	0.56423	0.62421
	K_6	0.94207	0.91056	0.60450	0.64414
	K_7	0.93911	0.91156	0.47872	0.65091
	K_8	0.93576	0.91247	0.5108	0.64533
	K_9	0.93201	0.91329	0.55748	0.62822
	K_{10}	0.92785	0.91403	0.60000	0.60000



(a) $g_1 = 0.6, g_2 = 0.4$ (b) $g_1 = 0.4, g_2 = 0.6$

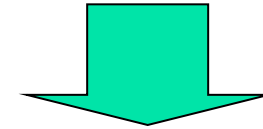
Fig.4 The evaluation indexes curves



(a) $g_1 = 0.6, g_2 = 0.4$ (b) $g_1 = 0.4, g_2 = 0.6$

Fig.2 The evaluation indexes curves

UOF本质是求取光谱信息评价指标 E_{sp} 与空间分辨率评价指标 E_{HF} 或平均梯度指标 AG 间的交点



$$M_1 = g_1 \times e_1 + g_2 \times e_2 \quad (14)$$

Here, $e_1 = E_{sp}$ and $e_2 = E_{HF}$. And the important measures are corresponding to the g_1 and g_2 previously.

利用模糊积分可以有效的综合光谱信息指标和空间分辨率两个单因素指标

The peak point is the maximum value $k_5 = k_{opt} = 0.682$ in this curve F. Under this way, the fused result has the maximum spatial resolution while the color distortion keeps least

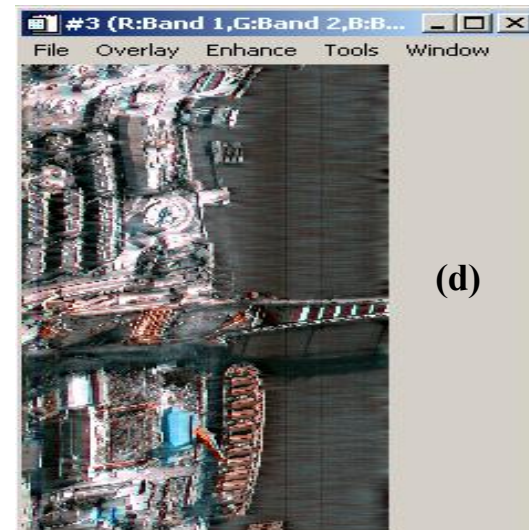
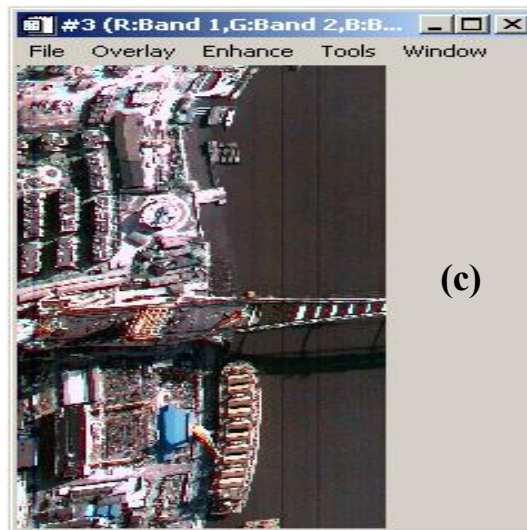
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Tab.3 The Compare evaluation indexes for fused images

	Band	Fig.3		Fig.5	
		CORR	AG	CORR	AG
IHS	R	0.5624	10.6146	0.4214	17.5486
	G	0.4644	11.3663	0.5112	16.4781
	B	0.5060	9.5875	0.5124	14.8623
FOF	R	0.8488	8.9448	0.7878	16.9718
	G	0.7691	9.4102	0.8040	15.3258
	B	0.8247	7.9353	0.7986	14.0322



— 基于模糊积分 的最优融合



PHI和6000元全色CCD图像数据的融合

(a) 6000元全色CCD影像

(b) PHI多光谱影像

(c) WT方法得到融合图像

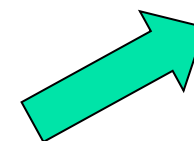
(d) FOF融合方法得到融合图像



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一基于模糊积分的最优融合优点

计算效率 + 光谱保持 + 空间分辨率



不同图像融合算法运行时间的比较
(注: 运行于PIII866 PC机, 图像大小为: 166×330)

	WT	IHS	UOF	<u>FOF</u>
计算时间	0.5723s	0.4205s	1.4572s	0.6121s



- Thanks!
- Questions?

