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Review on Different PAN Sharpening Methods

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Abstract: In current technological development in electronics era have promoted real time remote sensing system to collect fine image resolution over the ground. The earth observation satellite such as Quick-bird, IKONOS, landsat etm+, CALIPSO uses the on-board optical imaging sensor while designing these sensors there are some limitation and in order to meet these limitations trade-off between the spatial resolution spectral resolutions and signal to noise ratio is made. Because of this reason optical system provides the data which consists of low resolution multispectral image and high resolution panchromatic image. High resolution colour image can be obtained from these available images by the process called as pan sharpening. This process combines low resolution multispectral image with high resolution PAN image to produce the resulting image which corresponds to multispectral images with same resolution as that of PAN image. This method provides effective way to obtain colour image with high spatial resolution for the better visual image from remote sensing system. In this paper the review of different pan sharpening methods is taken.
Keywords: Satellite image, PAN image, MS image

I. INTRODUCTION

This Pan sharpening is post processing operation provides the enhancement to the remotely sensed images by remote image sensing satellite. The goal of pan sharpening is to obtain images that would be captured by an ideal system which should have both good spectral and spatial resolution. Remote sensors in satellites provides images about the surface of the earth which are use full for different remote sensing application such as land cover classification, weather forecasting, environmental monitoring. It is difficult to acquire a high resolution MS image directly due to physical limitations of earth observation satellite. Satellites uses two separate cameras to acquire low resolution multispectral (MS) Images and high resolution panchromatic (PAN) image. In order to collect the spectral and spatial information from these images these two images are fused to get high spectral and high spatial resolution image. This fusion technique is commonly called as pan sharpening.

II. DIFFERENT METHODS

Various techniques are used for pan sharpening methods Such as CS (compressed sensing), MRA(Multi resolution analysis), hybrid method, different variant of MBO(Model based optimization), MMSE pan sharpening, HFII (high frequency injection), IHS (intensity-hue-saturation), Sparse image fusion, Two-step sparse coding.

A. *Compressed Sensing*

CS technique uses the principle of spar-sity regularization. Using this principle compressible signal can be obtained from global linear sampled data. Sampling of LR and HR images is done and sampled data is arranged in matrix form which is called as degradation model. This is nothing but the global linear sampled data. This is also referred as measurement matrix. This method undergoes restoration problem that can be resolved by using basic pursuit algorithm. CS is per pixel transformation framework.

B. *Image Fusion in CS Method*

In order to go for pan sharpening first it is required that the both MS and PAN images belongs to same domain. So in this method noisy low resolution PAN image is obtained from its high resolution PAN image by the process called decimation. MS images consists of four spectral band named red (R), green (G), blue (B), near infrared (NIR). These images are fused with obtained low resolution PAN images this can be done in raster scan methods which covers scanning from left top to right bottom pixel by pixel such that four pixel in PAN images and one pixel in MS images. These patches Ypan and Yms obtained from PAN and MS images respectively and combined in a vector say Y. the spar-sity regularization can be covered by BP method. This is the sparse representation of fused MS image patch acquired from the dictionary. Dictionary consists of sparse representation of parameterized waveforms Gabor dictionaries and cosine packets are normally used parameterized 2-D waveforms of wavelets. In order to get better result non-parameterized application orientated dictionaries can developed. But the dictionary learning is difficult n time consuming so normally theses dictionaries can be acquired by sampling images which is under the observation.

C. Arsis

Popular ARSIS concept assume that missing spatial content in MS images can be recovered from high frequencies of the PAN images. To extract these high frequencies of PAN images discrete wavelet transform (DWT), a trous wavelet transform (ATWT) ,contour lets, support value transform, additive wavelet luminance proportional(AWLP) are used.

D. MRA (Multi Resolution Analysis)

Multi resolution analysis (MRA) uses the spatial filter to obtain details from PAN images which is to be injected in HS data under proper condition this method provides temporal coherence, spectral consistency, robustness to aliasing on the other hand implementation of this technique put limitations on design and coefficient calculation of spatial filter. This method can be represented as

$$X^K = Y_H^K + G_K \times (P - P_L)$$

Where K=1,2…..m_λ, P_L is low pass edition of P, $(P - P_L)$ is high pass edition of P also called detail image, × denotes element wise multiplication, G_K is gain coefficient which can be defined as1) $G_K = 1$ this 1 indicates appropriate size matrix with all 1 element 2) $G_K = Y_H^K \div P_L$, where ÷ denotes element wise division this method of selecting coefficient is also called high pass modulation, Y_H^K represents MS image, X^K represents estimate of image.

E. Hybrid Method

This method combines CS and MRA methods

Guided filter PCA (GFPCA) :- the major challenge while fusion of MS and PAN images is to maintain appropriate balance between spectral and spatial preservation to overcome this problem guided filter is used. CS will cause the spectral distortion so instead of this GFPCA is used. This uses the HR PAN image to guide the filtering process so that is can store the spectral information from MS images as well as spatial information from filtering process. GFPCA uses PCA to speed up this process by de-correlating the bands of MS images

F. MBO (Model Based Optimization)

MBO is formulated based on explicit physically-motivated sensor model for the panchromatic and spectral channels. This method estimates the HR multispectral image in combination with the minimization of an objective function which is formed as the sum of three terms that is a)a new regularization term that relates high frequency details from PAN image into the estimated HR spectral image reducing to constrained least squares regularization in the absence of correlation b) a squared error term corresponding to the panchromatic observational model c)explicit models for both spatial blurring and down-sampling the observational model for the LR spectral images.

Firstly physical model is obtained for multispectral imaging system. Here spatio-spectral distribution r(□,ᴅ;**λ**) is derived this distribution is function of light intensity which is incident on image sensor planes which are required to capture PAN and multispectral images. Here **λ** represents the wavelength of light and (□,ᴅ) is the sensor image plane orthogonal co-ordinate system which is aligned in sensor sampling grid. Captured PAN image can be represented as convolution of point spread function (PSF) and spectral responsively of the PAN image along with noise. The main objective is to retrieve the HR spectral images from observed PAN and LR spectral images. PAN is obtained by sensor having an appropriate sampling interval. Suitable PSF for a particular channel is obtained by comparing with HR sampling lattice. Required HR spectral image is obtained by scaling PSF and is selected to match the PSF for the panchromatic channel. The problem while estimating these images is resolution enhancement. The PAN image also contains some high frequency information which is not present in LR spectral images. So in order to deal with these problems in discrete domain low pass filter on the lattice is provided which is followed by down sampling to the lattice. These information is represented in matrix stack format. This information is also called as partially aliased information that is now combined with the LR images. This process will provide the model for spectral correlation. Complementary high pass filter is defined for low pass filter and joint optimization is achieved for pan sharpening. Iterative minimization algorithm is used for this process. This method differs from the other method by how the filter is determined and the knowledge of PSF is used to combine HR and LR images and the spatial down sampling.

The MBO methods are having different approaches for pan sharpening. One of the method defines markov random field (MRF)

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inspired energy functional that is having minimized observation model. In this method it is assumed that captured images q*q spatial averages pixel. Transformation of edge information from PAN images to pan sharpened images is done by calculating spatial neighbourhood weight for the MRF. Another approach is regularized constrained least restoration in this method observed data is nothing but the interpolated edition of captured LR images. Standard linear spatially invariant representation along with the additive noise is used as restoration image for HR images. The restoration of the HR PAN images is obtained by minimization of objective function which additively combines the squared error in the given two observational models. This method purely works for smoothing.

Methods used in CS and MRA frameworks are more advantages over MBO framework because of computational complexity which increases the computational cost in MBO. But the quality of pan sharpening using MBO is predominant over computational cost.

G. Adjustable Model Based Fusion Method

In this method the relationship between required high spatial resolution MS images and captured low spatial resolution MS images and HR PAN Images are developed which provides image observation model. Using this observation model and by selecting proper density function fusion is obtained. Gradient descent algorithm is used fuse HR MS images.

Observed low spatial resolution MS images are represented in vector form as y_b having image size N1*N2 and high spatial resolution HR images are represented in vector form as x_b having image size M1*M2; M1=N1*L, M2=N2*L, where L refers the spatial scale difference in MS and PAN images and b stands for bth band of images. Observation model is given as, $y_b = DS_b x_b + n_b$; S_b is blur matrix, D is down sampling matrix, n_b is noise matrix. If blurring is ignored in fusion process this can be represented as $y_b = A_b x_b + n_b$; A_b is identity matrix. So the whole set can be represented as y=Ax+n.

Other observation model can be obtained by relating HR MS image x and HR PAN image z. it is represented in a way such that PAN is linear combination of HR MS image

z=C_x+□I+v where C is sparse matrix, □ is offset, I is identity matrix, v is noise. Offset can be calculated approximately from degraded PAN image and LR MS image.

Once the observation model is obtained next step is MAP estimation of x,y,z. This can be done as ẋ=arg maxp(x|y,z) and then by applying baye's theory different probability density functions(PDF) are acquired. This is followed by fusion model these PDF provides estimation for fusion of images. Huber-Markov image model can be applied in this process to preserve edge. Gauss-Markov and Laplacian image models are also employed during this process which will gives the smoothened images. The next step is optimization method which is done by using gradient descent method on fusion images. In order to apply the MAP fusion 2B regularization parameters are calculated. The observation model or different image model or probability density function provides the relaxation according to the images available this method is pronounced as adjustable model based fusion method.

H. MMSE PAN Sharpening

This method employs the optimization algorithm called minimum mean square error for pan sharpening of high resolution MS images so this method is named as MMSE pan sharpening method. This algorithm will minimize the squared error between captured MS image and degraded version of particular MS image with a scale factor same as that of PAN image.

This method undergoes the spatial degradation which can be treated by low pass filter whose frequency response matches with the modulation transfer function. Amplitude spectrum of the system point spread function is known as modulation transfer function(MTF).

This method uses the injection method there are two linear injection model single spatial-detail (SSD) and band dependent spatial detail (BDSD). SSD enhance all MS band whereas BDSD will focus on particular MS band. These models use the same framework for mmse spatial detail injection into MS image. In which MTF filtering of MS bands is done which will then undergoes the up-sampling in order to match the resolution with that of PAN image. MTF filtering of the PAN image is also done and from these two results mmse estimation is done which is to be used for injection process. Original MS images are also used for optimal parameter calculation. This optimal mmse estimation is injected in fusion process of MS and PAN images.

I. HFII (High Frequency Injection)

In order to preserve the spectral characteristics extracted high frequency samples are injected into MS images. In this each image is processed in a way that each output pixel is having value which represents the average of its all neighbor pixel. Any image can be represented as

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image(i,j)= LP(i,j)+HP(I,j) here LP represents the low-pass blurred image of original image

From this equation we can say as the neighbourhood size is going to increase LP hides the larger structure and HP will collect the small content missed by LP. So in this method spatial filter technique is employed to get the pan sharpened images. So to do this firstly MS image is up sampled to the size of PAN image then low pass filter is applied to PAN image this result is subtracted from original PAN image which provides high frequency information which is to be injected to each band of MS images.

J. IHS (Intensity-Hue-Saturation)

One classical method of pan sharpening is intensity-hue-saturation method which comes under the category of component substitution. This method uses the IHS colour space. This fusion method transfers captured image which is in the RGB space to IHS space and I band is exchanged with PAN image which is calculated as $I = \sum_{i=0}^{N} \alpha_i M_i$

Where M_i represents multispectral band, α_i=1\N, N stands for no of bands

Then up sampling and normalization is done in order to ensure mean and standard deviation lie within the same range. Then fused image is obtained as $F_i = M_i + (P - I)$ where P represents PAN image. So the results obtained by this method are having high spatial and low spectral resolution. In order to enhance the spectral quality adaptive IHS method is employed.

In adaptive IHS method to minimize the spectral distortion intensity band should closely approximate PAN image and this can be done by varying the value of α. And the fusion is done as

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

Where h(x) is edge detection functions. This edge detection and adaptive coefficient modification is commonly known adaptive IHS method.

K. Sparse Image Fusion

Sparse fusion is based on compressive theory. In this method images patches are represented using sparse signal representation. Dictionary is trained by using panchromatic image only so MS images are not required from sensor. As this method learn from the data available and as it is having the super resolution capability along with the robustness these methods are expected to provide higher spectral and spatial resolution with less spectral distortion. This method consists of dictionary learning, sparse coefficients estimation and HR multispectral image reconstruction. HR dictionary is obtained by tiling PAN image.HR PAN image is low pass filtered and down sampling is done on that this is now called as LR PAN image. This image and multispectral image are tiled into small patches with these pixel values arranged in matrix form gives the LR dictionary. Sparse coefficient vector α_k is estimated as

$$\alpha_k = \arg\min\{\lambda\|\alpha_k\|_1 + 1/2\|\tilde{D}\alpha_k - \hat{y}_k\|_2^2\}$$

Where $\tilde{D} = \begin{bmatrix} D_l \\ \beta P D_h \end{bmatrix}$ & $\hat{y}_k = \begin{bmatrix} y_k \\ \beta w_k \end{bmatrix}$

Where

D_l represents LR dictionary, D_h represents HR dictionary, matrix P represents the region of overlap between the current target patch and previously reconstructed ones, w_k represents pixel values of the previously reconstructed HR multispectral image patch on the overlap region, β represents weighting factor,$\boldsymbol{\lambda}$ represents standard lagrangian multiplier, y_k represents LR multispectral patch in the kth channel. Then HR multispectral image is reconstructed by using sparse coefficient as $x_k = D_h \alpha_k$.

L. Two-Step Sparse Coding

In this method the sparse representation is done by using coupled dictionaries. The main idea of this method is assumption of occurrence relation in up-sampled LR and HR image patch pair share the same sparse coefficients with respect to their own dictionaries. High resolution MS image is obtained by fusing LR MS image and PAN image. Coupled dictionaries are constructed by PAN image and its degraded image. HR PAN Image is down-sampled and blurred to get the LR PAN image which has same resolution as that of LR MS image. Patches are extracted from LR PAN Image and arranged in vector form to build matrix known as LR dictionaries. Same process is used to obtain HR dictionaries. Using the LR dictionary sparse representation of LR patch is done and fused patches are reconstructed with HR dictionary.

M. P+XS

This is variational method. In this method pan sharpened image is calculated by minimizing the energy function. Using gradient function it obtains the edge information of panchromatic image. The spectral information can be acquired by approximating the panchromatic image as a linear combination of multispectral band.

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M. VWP (Variational Wavelet PAN Sharpening)

This method combine two pan sharpening method to get pan sharpened image. These two methods are wavelet and P+XS method. The wavelet method used here will provide high spectral quality and energy function used in P+XS method provides clear edge information of pan image. VWP method is having the better spectral quality.

III. ANALYSIS

In comparing the spatial quality, it is relatively easy to judge spatial quality just by looking at the image. For example image 1 IHS demonstrate clear edges similarly all images follows the same. In order to go for more accurate results some metrics are used which are shown in the table given below. The spectral quality is more difficult to judge visually so different metrics are used to evaluate results. In all fused images IHS have higher colour distortion this is because of overusing the pan image. Looking at table 5 we can conclude from the metrics that VWP performs best spectrally.

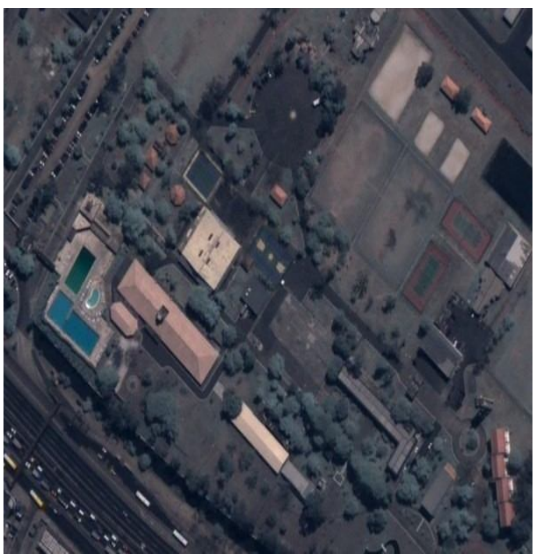
Image :- 1	
Multispectral 	Panchromatic 
IHS 	VWP 

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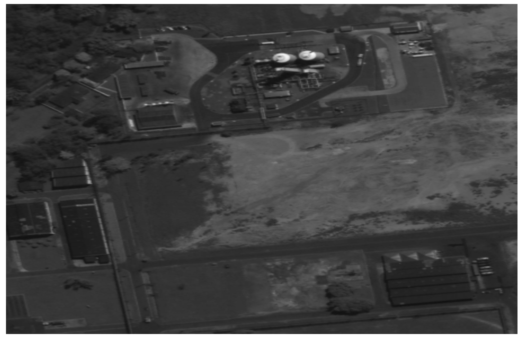
Image :- 2


Multispectral

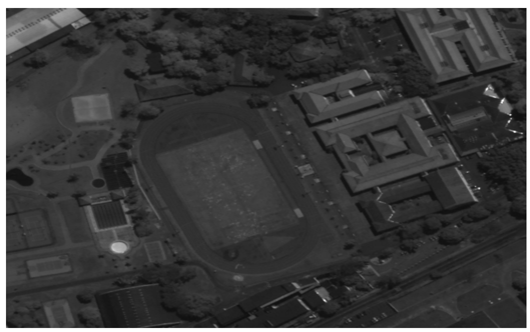

Panchromatic

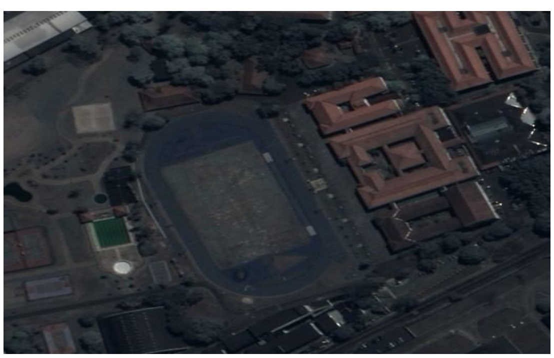

IHS


VWP

Image :- 3


Multispectral


Panchromatic


IHS


VWP

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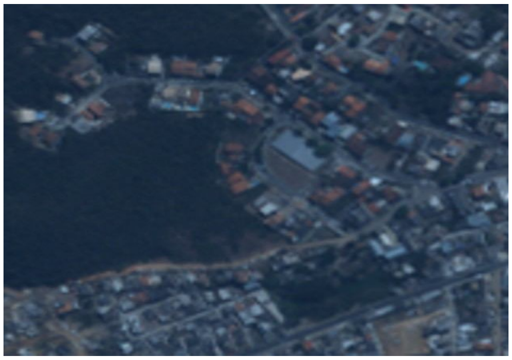
Image :- 4


Multispectral


Panchromatic


IHS


VWP

Following tables shows the performance parameters of above images which shows the values of CC, ERGAS, Qave, Rase, RMSE,SAM,SID and Spatial.

Table: - 1

	CC	ERGAS	Qave	RASE	RMSE	SAM	SID	Spatial
Reference Value	0	0	1	0	0	0	0	1
IHS	0.0352	6.8427	0.7144	23.8951	94.8065	5.1496	0.0252	0.9920
VWP	0.0280	1.7295	0.9912	7.0458	27.9552	1.3646	0.0015	0.8705

In above table performance parameter of image 1 is given.

Table: - 2

	CC	ERGAS	Qave	RASE	RMSE	SAM	SID	Spatial
Reference Value	0	0	1	0	0	0	0	1
IHS	0.1050	3.9794	0.7401	14.4064	59.3136	1.9123	0.0070	0.9814
VWP	0.0231	1.7669	0.9892	7.2208	29.7291	1.5062	0.0046	0.8366

In above table performance parameter of image 2 is given.

Table: - 3

	CC	ERGAS	Qave	RASE	RMSE	SAM	SID	Spatial
Reference Value	0	0	1	0	0	0	0	1
IHS	0.0418	7.4936	0.7079	26.3325	103.380	6.8840	0.0211	0.9897
VWP	0.0196	1.8833	0.9869	7.6152	29.8969	1.7611	0.0015	0.8377

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In above table performance parameter of image 3 is given.

Table: - 4

	CC	ERGAS	Qave	RASE	RMSE	SAM	SID	Spatial
Reference Value	0	0	1	0	0	0	0	1
IHS	0.0558	5.6599	0.7079	19.9838	73.1578	2.7761	0.0224	0.9962
VWP	0.0538	2.3775	0.9833	9.7017	35.5164	1.9511	0.0031	0.8654

In above table performance parameter of image 4 is given.

Table: - 5

	CC	ERGAS	Qave	RASE	RMSE	SAM	SID	Spatial
Reference Value	0	0	1	0	0	0	0	1
IHS	0.05945	5.9939	0.71757	21.15445	91.5377	4.1805	0.018925	0.989825
VWP	0.03113	1.9393	0.98765	7.89588	30.7744	1.64575	0.00268	0.85255

Table number five indicates the average values of all above four tables.

IV. CONCLUSIONS

Image pan sharpening is post processing method which fuses low spatial resolution but high spectral resolution MS image with high spatial and low spectral resolution PAN image. Pan sharpened image is having high spatial and high spectral resolution.

This paper summarizes different pan sharpening method. There is trade off in every method between the spatial and spectral resolution. The choice of the method depends on how fused images are used. VWP method performs best spectrally while IHS method performs best spatially.

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