High Spatial Resolution Hyperspectral Image using Fusion Technique

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Abstract—**Now a day's remote sensing imaging is extensively used in the study of land resources, surface geology, water resources, landslide study, forest study, urban development at large scale. Always there is a need to improve the spatial and spectral information of remote sensing data. This can be done either by building new satellites with high resolution power or by using image processing techniques. Building a new satellite with high power is much more expensive, so it is an advantage of using image processing techniques. Hyperspectral imaging sensor provides better spectral resolution, but provide poor spatial resolution and multispectral imaging sensor provides good spatial resolution but provide poor spectral resolution. There are many fusion techniques such as Gram Schmidt Pan Sharpening, Principal Component Transform, High Pass Filtering are used to sharpen Multispectral Image with panchromatic image. To sharpen the hyperspectral image we are trying to fuse the HSI with MSI with the existing techniques and are quantified using Mean Square Error, Peak Signal to Noise Ratio, Entropy, and Universal Image Quality Index.**

***Index Terms*—FLAASH, Hyperspectral, QUAC, Image Fusion, and Multispectral.**

I. INTRODUCTION

The art of gaining reliable information about physical substances and the environment of the earth is called remote sensing. Remote sensing is the process of capturing the digital data about the earth without directly in contact with the sensor system [1]. Remote sensing images are acquired from aerial platform or satellite platform. Remote sensing satellites are the one which captures hyperspectral image (HSI) and multispectral image (MSI). Usually, the images are captured in the visible region, but whereas MSI are the one which are not only captured in the visible region, but also in Near Infrared region and Short Wave Infrared (SWIR) region.

A MSI is one that acquires image data at wide range distinct frequencies throughout the electromagnetic spectrum. Images are captured at distinct frequencies using an instrument which is sensitive to a particular frequency. MSI consists of 4 to 12 bands which are captured in the wider bandwidth of wavelength around 100nm. Some of the multispectral sensors are Linear Imagine Self Scanning System (LISS), Multispectral Imagery (MSI), Ionosphere Measurement Sensor (IMS), Infrared Multispectral Scanner (IR-MSS) and Ionosphere Plasma and Electrodynamics Instruments (IPEI).

Even HSI are the one which are not only captured in visible region, but also in near infrared region and SWIR region. HSI consists of 10s to 100s of bands which are captured in continuous spectral channels with a smaller bandwidth of wavelength around 10 nm [2]. Some of the sensors are Hot Spot Recognition Sensor System (HSRS), Infrared Atmospheric Sounding Interferometer (IASI) and Hyperion.

Enhancement of HSI has been a major concern for the remote sensing community which enables the detection of endmember easy [1]. With respect to MSI, HSI has a lower spatial resolution. HSI has high spectral resolution, and cover a wide range of wavelengths. The HSI has high spectral resolution and MSI has high spatial resolution. The spatial resolution of the HSI is comparatively lower than that of the MSI. Fusion is a technique in which the spatial resolution of HSI can be increased. High spatial resolution HSI has many applications such as target detection, boarder surveillances, precision agriculture and vegetation, hydrology, environmental mapping, monitoring and change detection and mine detection [3].

There are many fusion techniques such as Gram-Schmidt Transformation, Color Normalized Transform etc., are used to fuse MSI and panchromatic image, which enhances the spatial resolution of MSI that make target detection possible.

Shalima et al., in [8] discussed different image fusion technique for RGB image have been reviewed. Here they have considered RGB image of lays packets, one image is focused on right side and blurred on lift side and second image is visa-versa. And they have applied different fusion methods such as average method, PCA, IHS transform, High Pass Filtering (HPF), Discrete Wavelet Transform, Discrete Cosine Transform on these two images. Each method has its own benefits and drawbacks. In these methods some improves the clarity of the image to certain extent and most of them suffer from the problem of roughness of edges of the image and color arte facts. These problems can be overcome by integrating gray world based color correction algorithm DCT fusion.

A novel method called sparse representation for the fusion of HSI and MSI is proposed in [5]. HIS is captured by reflective optics system imaging spectrometer (ROSIS), which consists of 115 bands and MSI is 4 band data acquired by IKONOS over the urban area, the University of Pavia, Italy. Compared to other fusion techniques the proposed technique offers less spatial error and lesser spectral distortion. Spare fusion is quantified using RMSE, UIQI, spectral angle mapper (SAM), ERGAS with other fusion techniques such as wavelet MAP, CNMF, HMC, and maximum a posteriori (MAP). The proposed method has reasonable computation complexity.

In [10] the recital of FLAASH and QUAC atmospheric corrections are evaluated. The FLAASH and QUAC atmospheric correction is done on HSI taken from Hymap aircraft-borne sensor on 31st of May 2003, in Davis, California region. In recovering of reflectance spectra of the object QUAC also perform equal good as FLAASH algorithm so, it can be used as a matched filter tool to identify the bright object in an image. But in the dark object detection FLAASH algorithm shows better performance than the QUAC.

Shashidhar Sonnad [6] furnished a survey on various image fusion algorithms of MS and PAN images such as, Brovey transform, Principal Component Analysis (PCA), Intensity-Hue-Saturation(IHS) transform, High Pass Filtering, Wavelet transform, Integration of different transform methods with IHS , fusion process is based on PCA and feature product of Wavelet transform, Fourier transform, General Intensity Hue Saturation (GIHS) transform, Optimal Filter design, modified Wavelet Averaging Merging method and modified Bi-cubic Interpolation method in non-subsampled Contourlet transform, improved Principal Component Analysis and Intensity-Hue-Saturation merges based on Wavelet decomposition. They have applied all these fusion techniques on different satellite images and evaluated their performances and concluded that no particular fusion method is excellent compared to others, the best technique is selected contingent upon the application.

Yuhong Ding and Yanhui Wang [7] discussed an approach that obsoletes the multi-source data fusion by retaining the spectral information and enhancing the resolution of the muti-source data image. Brovey, PCA, Multiplicative and IHS are used to fuse poor resolution multi-source data with better resolution panchromatic images. Here the multi-source data is QuickBird and a pan image is SPOT5. The results are quantified using qualitative analysis and objective quantification. The assessment indicates that both Multiplicative and IHS retains the colour. For the environmental study of urban and rural area, multiplicative fusion is best suitable. PCA depicts more details of image than Brovey fusion technique, and the image is clearer in PCA. Brovey is more appropriate for target separation, particularly the greenbelt. All these fusion techniques are quantified using the average gray, standard deviation and mean of fused image.

Endmember detection is very important for hyperspectral imagery analysis. However, there is no one method that is good in all situations for all cases. The attempt to fuse the hyperspectral image with the multispectral image, to obtain a spatially and spectrally rich hyperspectral image is reviewed.

Section II discusses the methodology adopted, pre-processing and fusion techniques are explained in section III. Hyper and multispectral images are considered in section IV. Results are discussed in the section V and conclusions with future work in section VI.

II. Methodology

The objective of the work is to obtain spectrally and spatially rich image by fusing HSI and MSI. Flow Chart for fusion of HSI and MSI is as shown in Fig. 1.

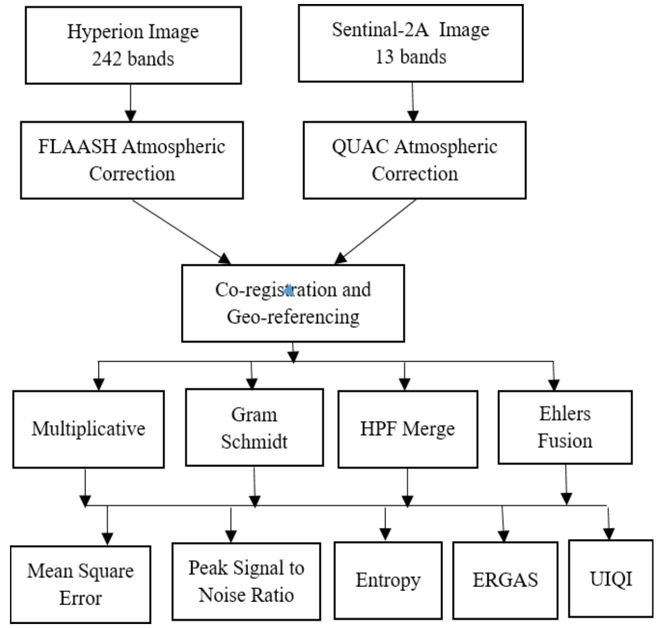


Figure 1: Flow Chart for fusion of HSI and MSI.

The following are the steps to obtain spatially rich HSI:

i. Study of HSI and MSI.
ii. Crop HSI of 197 samples, 158 lines and 242 bands. And Crop MSI of 590 samples, 474 lines and 7 bands of same region.
iii. Implementation gain on HSI and MSI.
iv. Apply pre-processing techniques such as atmospheric correction on HSI and MSI. FLAASH on HSI and QUAC on MSI.
v. Co-registration and geo-referencing of MSI and HSI.
vi. Fusion of MSI and HSI to obtain spectrally and spatially rich image.
vii. Fused image is quantified by Mean Square Error, PSNR, Entropy, ERGAS and UIQI.

III. Pre-processing and Fusion techniques

A. Atmospheric Corrections

Remote sensing satellites when captures an image of earth surface it not only contains the information of earth surface but it also includes the information of the atmosphere present above the earth surface. For the perfect analysis of the image atmospheric information is not required only the reflectance information from the earth surface. The atmosphere consists of water vapors, aerosols, and clouds. To remove these atmospheric components some type of atmospheric corrections is required. Atmospheric correction models that can be applied to MSI and HSIs are Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) and QUick Atmospheric Correction (QUAC).

1) Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes Model

FLAASH uses first-principles to do atmospheric correction. It can correct the image wavelength ranging from VNIR and SWIR up to 3000 nm. The MODTRAN4 radiation transfer code is integrated in FLAASH. FLAASH is capable of correcting adjacency effect. It has advanced techniques to handle stressed atmosphere such as presence of cloud. It can adjust the spectral polishing for artefact suppression. It also can recover water vapors and aerosols in atmosphere, if the bands of the image are in appropriate wavelength [10].

2) QUAC for Sentinal-2

Quick Atmospheric Correction is a type of atmospheric correction that can be applied for frequency ranging from VNIR to SWIR. Unlike other atmospheric correction, QUAC does not require any extra atmospheric component information. It does atmospheric correction by directly finding atmospheric components from the data confined in the image (observed pixel spectra). QUAC computational speed is fast related to any other first-principles approaches [14].

B. Fusion Techniques

An image with spatially rich of 10m and spectrally rich of 72 bands has been restored from a 30m resolution HSI with 242 bands and a 10m resolution MSI with 7 bands. The hyperspectral bands are selected with respect to the particular band range of the multispectral sensor. Some of the fusion techniques that are applied to HSI and MSI to get spatially rich HSI are discussed next.

1) Multiplicative Fusion

The Multiplicative model fuses two images by multiplying every pixel in every band of the hyperspectral data by the corresponding pixel of the multispectral data, which fall in that particular wavelength band. This fusion technique is a simple multiplication of set hyperspectral band with the corresponding band in multispectral of specific wavelength.

The benefit of this technique is that it is direct and easy to implement. But the drawback is that by multiplying separate set of information with different set of bands the spectral characteristics of the original image is not retained. The spectral characteristics are amplified randomly. So the spectral signatures of the endmember vary than the original spectral signature of the endmember.

2) Gram-Schmidt Spectral Sharpening

Gram-Schmidt Spectral Sharpening uses modified Gram-Schmidt orthogonalization process in which the set of HSI band are made orthogonal with respect to MSI. Here both images should be co-registered. The modified Gram-Schmidt orthogonalization process is the one which transforms the set of linearly independent vector $\{X_1, X_2, \ldots, X_n\}$ into a set of orthogonal vectors Q_i ($i=1,2,\ldots,n$) such that each vector is a linear combination of an independent vector [4]. The main drawback of this process is that spectral sensitivity of sensor should be known.

3) High Pass Filter Resolution Merge

HPF resolution merge uses High Pass Filtering method to fuse HSI and MSI to get spatially rich HSI, which results in detailed and realistic representation of original HSI. HPF resolution merge retains most of the spectral data of HSI because most of the spectral information is involved in low spatial frequencies of HSI. So the cut off frequency should be selected in such a way that it shouldn't affect the spectral information of the HSI.

4) Ehlers Fusion

The main idea behind Ehlers fusion is to retain the spectral information of the HSI after the fusion of a set of N band in HSI with the single band of MSI. In a set of N bands first 3 bands are considered as RGB then it is transformed into Intensity-Hue-Saturation (IHS). Fast Fourier Transform (FFT) is applied to the pan band of MSI and passed through low pass filter. The resultant image is added with the set of HSI for which FFT is applied and filtered through HPF. The summed image is considered as intensity band and converted back to RGB image. This process repeated to all bands of HSI. Flow chart of Ehlers fusion is shown in Fig. 2.

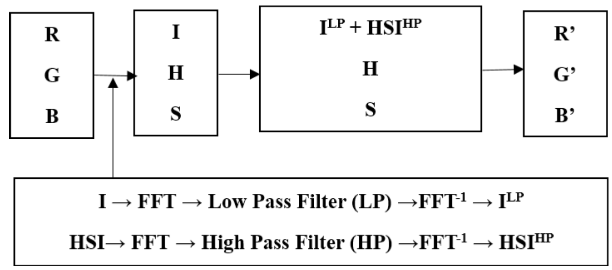


Figure 2: Flow Chart of Ehlers Fusion.

IV. Hyperspectral and multispectral image

The study area choosen is Bengaluru, which is situated on 12.557403 - 13.451806 N latitude and 77.600237 - 77.882211 E longitude as shown in Fig. 3(a) and Fig. 4(a). Bengaluru is located in south India on the Deccan Plateau, at an elevation of 920 m (3018.37 feet) above sea level. It has a usual climate with an annual average temperature of 16°C to 35 °C.

A. Hyperspectral Image

The HSI that is selected is Hyperion and is captured by Earth Observing-1 (EO-1) satellite. Purpose of Hyperion is to collects 242 unique spectral bands ranging from 357 to 2576 nm with a 10 nm bandwidth, with a spatial resolution of 30 meters [9]. Out of 242 bands, only 196 bands are calibrated and rest all are not calibrated and set to zero, in which 1-76 band falls in VNIR region and 77-242 falls under SWIR region. The image consists of 256 samples, 3129 lines and 242 bands. Fig. 3 (a) shows the Hyperion image in SWIR region.

B. Multispectral Image

European Space Agency (ESA) and Airbus Defence built a satellite called Sentinel-2. Sentinel-2A satellite is controlled by ESA and it captures a MSI. The satellite is placed at an altitude of 786 Km. It consists of 13 spectral channels of diverse spatial resolution of 10m, 20m and 60m. These spectral bands fall in VNIR to SWIR wavelengths. And wavelength ranges from 400nm to 2200nm. The image captured by this satellite is of 100Km × 100Km, projection is Universal Transverse Mercator (UMT) and datum World Geodetic System 1984 (WGS84). The image that is obtained by USGS is in the form of GeoTIFF. Fig. 4 (a) shows the cropped Sentinel image.

V. Results and Discussion

A Hyperion HSI cropped image of 158×197×72 and Sentinel-2A MSI cropped image of 474×590×7 is considered. The pre-processing technique such as atmospheric correction is applied on these cropped images. FLAASH atmospheric correction is applied on Hyperion image, the resultant of FLAASH on Hyperion is as shown in Fig. 3. QUAC atmospheric correction is applied on Sentinel-2A image shown in Fig. 4(b). Atmospherically corrected images were geo-referenced and co-registered. Fusion techniques such as Multiplicative, Gram Schmidt Spectral Sharpening, HPF Resolution Merge and Ehlers Fusion are applied on these images. Hyperspectral bands are selected with respect to the particular band range of the MSI for fusion. Table I lists which bands of HSI are fused with MSI according to wavelength. Resultant of all fusion techniques is as shown in Fig. 5. Fused images are quantified using MSE, PSNR, Entropy, ERGAS and UIQI:

1) *Mean Square Error*

The Mean Square Error (MSE) characterizes the collective squared error between the fused image and the original image. Lesser the value of Mean Square Error signifies lower the error is.

$$MSE = \frac{\sum_{(s,l,b)}\left[I_{1(s,l,b)} - I_{2(s,l,b)}\right]^2}{n_x n_y n_\lambda} \quad (5.1)$$

Where $I_{1(s,l,b)}$ and $I_{2(s,l,b)}$ are the value from the sample s of line l in the spectral band b of the fused and original image I_1 and I_2 respectively [13]. According to the results obtained the Gram Schmidt Spectral Sharpening obtains less MSE which means the best fusion and Multiplicative fusion results in worst fusion technique and it is represented in plot as shown in Fig. 6(a).

2) *Peak Signal to Noise Ratio*

The Peak Signal to Noise Ratio (PSNR) is calculated in decibels and it evaluates the peak signal-to-noise ratio, in between the images. This ratio is used for quality measurement between the original and the fused image. Higher PSNR signifies better the quality of the fused or sharpened image. PSNR is calculated using (5.2).

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE}\right) \quad (5.2)$$

where R is the highest variation from the original image/HSI to fused image.

Higher the values of PSNR better the fused image [13]. According to the results obtained the Gram Schmidt Spectral Sharpening obtains high PSNR which means the best fusion and HPF merge results in worst fusion technique and it is represented in plot as shown in Fig. 6(b).

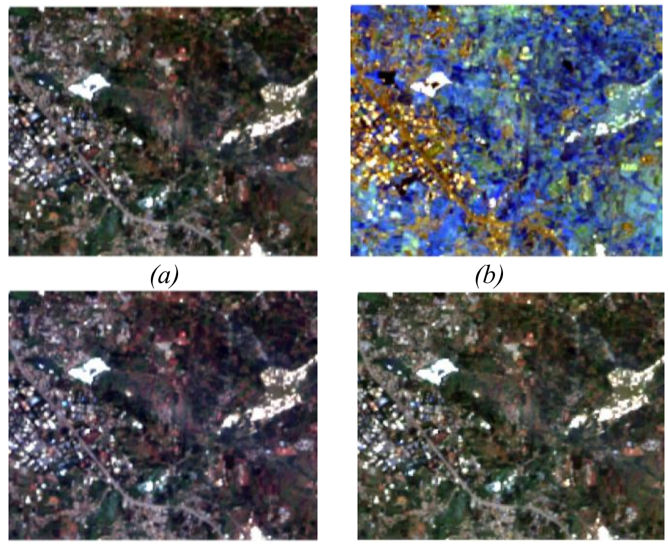
3) *Entropy*

Entropy measure the information contained in the image. Deviation of entropy between the original and fused image should be small, then the fusion is better. Entropy is expressed as in (5.3)

$$Entropy = -\sum_i \sum_j p(i,j) \times \log_2 p(i,j) \quad (5.3)$$

where p represents the histogram counts [13].

According to entropy definition the Gram Schmidt Spectral Sharpening shows better results and multiplicative shows the worst result and plot is shown in Fig. 6(c).

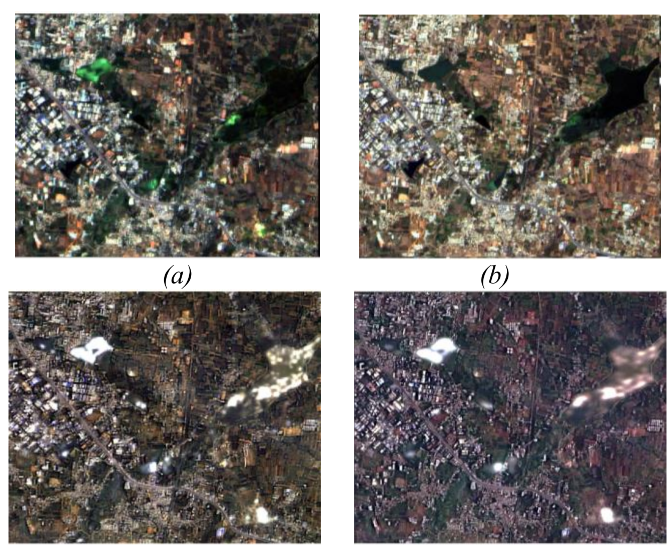


(a) (b) (c) (d)

Figure 3: (a) Hyperion Cropped SWIR (29,21,11),(b) Hyperion Cropped VNIR (204,150,93), (c) Gain Corrected Hyperion, (d) Hyperion FLAASH Atmospheric Corrected.

(a) (b)

Figure 4: (a) Sentinel-2 Cropped Image, (b) QUAC Atmospheric Corrected Sentinel-2 Image.



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

Figure 5: Final fused images of (a) Multiplicative Fusion, (b) Gram-Schmidt Spectral Sharpening, (c) HPF Resolution Merge, and (d) Ehlers Fusion.

TABLE I: MSI BAND FUSED WITH HSI BANDS

Wavelength in nm	Sentinel-2A band	Hyperion bands
440-538	2	9-19
537-582	3	20-24
646 684	4	29-34
694-713	5	35-38
760-908	8	40-62
1539-1682	11	139-154
2078-2320	12	192-198

4) Erreur Relative Globale Adimensionnelle de Synthese

ERGAS is used to check the spectral feature of the fused image and was proposed by Wald. ERGAS analysis is independent of units, independent of image resolution and independent of number of bands in image. The ERGAS index between fused image and original image is given by

$$ERGAS = 100\,\frac{f}{h}\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{RMSE(B_i)}{\mu(i)}\right)^2} \qquad (5.4)$$

where f and h denote spatial resolution of fused and original images, i indicates the position of each band, N denotes the number of spectral bands, RMSE(B_i) indicates the root-mean-square error (RMSE) for i^{th}-band between fused and original images, and μ(i) denotes the mean of i^{th}-band of original image. The value closer to zero better will be the spectral quality of the fused product [11].

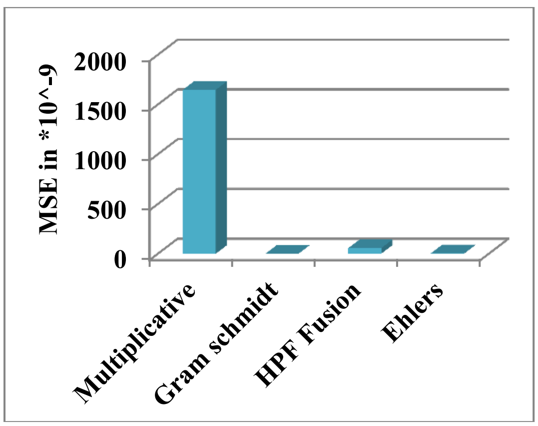


Figure 6 (a): Plot of MSE in nano units. Gram-Schmidt Spectral Sharpening shows better result.

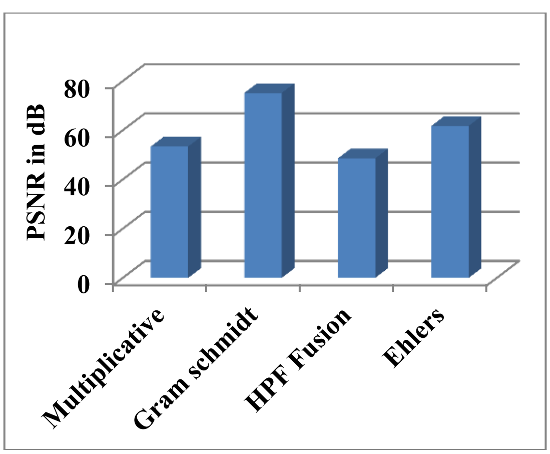


Figure 6 (b): Plot of PSNR in decibel. Gram-Schmidt Spectral Sharpening shows better result.

ERGAS value for all the fused images is calculated and the results are symbolised below in the form of graph as shown in Fig. 6(d). According to ERGAS Gram Schmidt Spectral Sharpening shows better results and multiplicative bad.

5) Universal Image Quality Index (UIQI)

Wang and Bovik proposed a model to compute image distortion using three factors such as contrast distortion, luminance distortion and loss of correlation. If x is fused image and y is HSI are represented in real valued sequences x = {x_1,…,x_n} and y = {y_1,…,y_n},$\bar{x}$ is average of of the fused image, $\bar{y}$ is average of the HSI, σ_x^2 is the variance of fused image, σ_y^2 is the variance of HSI and $\sigma_{xy}$is the covariance of fused and HIS. UIQI can be computed using

$$Q = \frac{\sigma_{xy}}{\sigma_x\,\sigma_y}\,\frac{2\bar{x}\,\bar{y}}{\bar{x}^2+\bar{y}^2}\,\frac{2\sigma_x\sigma_y}{\sigma_x{}^2+\sigma_y{}^2} \qquad (5.4)$$

Q = correlation * (luminance) * contrast

The final value of the quality metric is normalized between [0, 1]. The overall normalized UIQI is given by

$$Q = \frac{1}{N \times M}\sum_{i=1}^{N}\sum_{j=1}^{M} Q_{ij} \qquad (5.5)$$

The value closer to one, better will be the spectral quality of the fused product [12]. The UIQI value for all the fused images was calculated and the results are represented below in the form of graph as shown in Fig. 6(e). According to UIQI HPF merge shows better results and multiplicative shows the worst result.

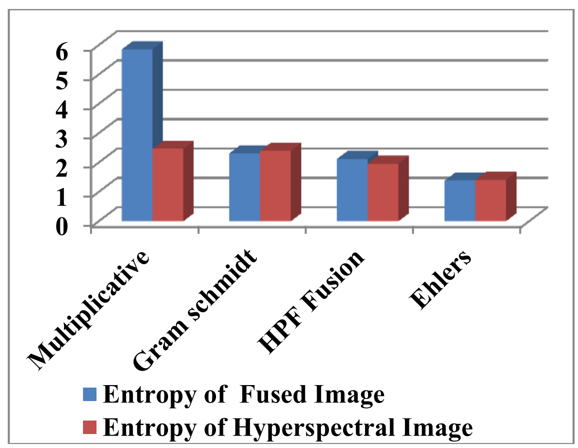


Figure 6 (c): Entropy of fused image and HSI. Gram-Schmidt Spectral Sharpening shows better result.

Quantification of various fusion techniques are discussed and listed in Table II.

TABLE II: QUANTIFICATION OF DIFFERENT FUSION TECHNIQUE

Fusion Methods	MSE in 10^{-9}	PSNR in dB	ERGAS	Entropy of FI	Entropy of HSI	UIQI
Multiplicative	1646.9	53.3998	27.405	5.8557	2.4634	0.0309
Gram Schmidt	0.12519	75.1802	0.3649	2.3153	2.3961	0.7630
HPF Fusion	55.441	48.5722	7.7523	2.1229	1.9604	0.7664
Ehlers	4.3148	61.7792	0.8355	1.3806	1.4071	0.5258

Note: FI = Fused Image.

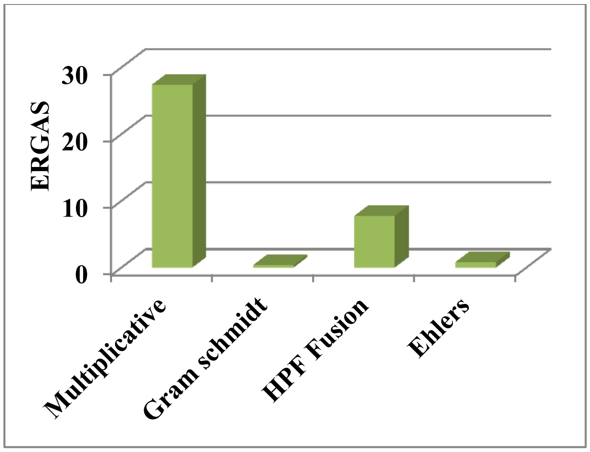


Figure 6 (d): Plot of ERGAS. Gram-Schmidt Spectral Sharpening shows better result.

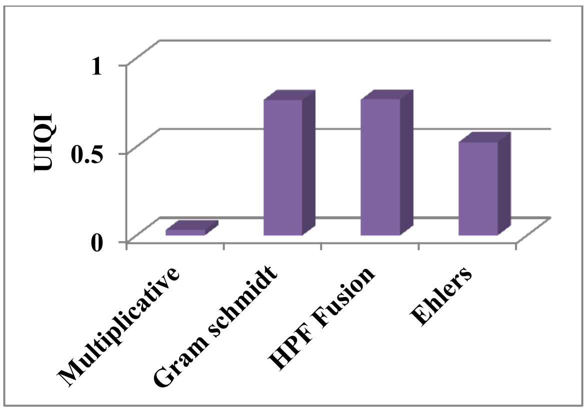


Figure 6 (e): Plot of UIQI. HPF Resolution Merge shows better result.

VI. Conclusion

In this paper, we have taken HSI and MSI of an urban area in Bengaluru region. FLAASH atmospheric correction is applied on HSI which is captured by Hyperion sensor. QUAC atmospheric correction is applied on MSI captured by Sentenial-2A. Fusion techniques such as Multiplicative, Gram Schmidt Spectral Sharpening, HPF Resolution Merge, and Ehlers Fusion are applied to the atmospherically corrected image. Fused image is quantified using MSE, PSNR, Entropy, ERGAS and UIQI. In our simulation fused image with Gram Schmidt Spectral Sharpening has given best fused image with respect to MSE, PSNR, Entropy and ERGAS, but HPF Resolution Merge fused image shows better results for UIQI parameter is tabulated in Table II. Hence, Gram Schmidt Spectral Sharpening can be adopted for HSI and MSI fusion for the urban area to obtain high spatial resolution hyperspectral image.

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