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Study of Pixel Based Image Fusion Algorithms in Remote Sensing

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Abstract— Image fusion is an image processing technique that can combine multiple images of the same scene with complementary or redundant information to generate a new composite image with better quality and more features which can provide a better interpretation of the scene than each of the single sensor image can do. But in Remote Sensing the term "image fusion" covers multiple techniques used to combine the geometric detail of a high-resolution panchromatic image and the color information of a low-resolution multispectral image to produce a final image with the highest possible spatial information content while still preserving good spectral information quality. Here, a panchromatic image from CARTOSAT-I and a multispectral image from LISS-IV (ResourceSat) are fused to produce an image that has both high spatial and high spectral resolution. Various Arithmetic, Color based and Statistical algorithms are used for fusion process. Their performances are evaluated quantitatively and qualitatively by means of various indices including Correlational Coefficient, Entropy, Signal-to-Noise Ratio and Normalized Root Mean Square Error.

Keywords— Remote Sensing, Image Fusion, Panchromatic Image, CARTOSAT, Multi-spectral Image, LISS-IV, Performance Evaluation Methods

I. INTRODUCTION

The field of remote sensing is associated with an increasing amount of imagery data, mission after mission. Such an increase makes the application of image fusion techniques in remote sensing important. Remote sensing is the "non-contact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or spacecraft, and the analysis of acquired information by means of visual and digital image processing". As the definition suggests, the field of remote sensing is associated with substantial amounts of visual data originating from a broad range of sensors which vary in their spectral, spatial, and temporal characteristics. Examples of such sensors are Panchromatic sensor (PAN), Multi-Spectral sensor (MS) (coastal blue, blue, green, yellow, red, near infrared), hyper-spectral sensor (100s of bands), Light Detection and Ranging (LIDAR), and Synthetic Aperture Radar (SAR). With such diverse and huge amounts of data, image fusion techniques can play a vital role in remote sensing. Image fusion aims at combining multi-source imagery into a single information representation with higher quality. The subsequent sections of this paper are organized as follows. Section II introduces to various Image Fusion Algorithms and their results on fusion of a CARTOSAT and a LISS-IV image are given for qualitative comparison. Section III quantitatively evaluates the performance of these techniques using various indices. It is subsequently followed by the Conclusions section.

II. FUSION ALGORITHMS

Data fusion provides several advantages: preservation of computer storage space; enhancement of aesthetic and cosmetic qualities; improvement of spatial resolution; and analytical improvements. Each reason for data fusion relies on the following premise--for a data fusion model to be effective, the merged images should retain the high spatial resolution information from the panchromatic (Pan) data set while maintaining the basic spectral record of the original multispectral (MS) data. Many methods have been developed in the last few years producing good quality merged images. The pixel image fusion techniques can be grouped into several techniques depending on the tools or the processing methods for image fusion procedure. It is grouped into three classes: 1) Color related techniques, 2) Statistical, 3) Arithmetic/Numerical, and combined approaches. For this study, images used as input for the fusion are shown in Figure 1. Resolution of PAN image from CARTOSAT-I is 2.5 m and that of MS image from LISS-IV is 5.8 m. PAN image of dimensions 400 x 400 pixels is taken and corresponding MS image has been resampled into the same size using 'Nearest Neighbor' method. As an alternative 'Bi-linear' or 'Cubic-Convolution' methods can also be used.

A. Multiplication (MLT)

- The Multiplication model combines two data sets by multiplying each pixel in each band of the MS data by the corresponding pixel of the Pan data. To compensate for the increased Brightness Values (BV), the square root of the mixed data set is taken. The square root of the multiplicative data set, reduces the data to a combination reflecting the mixed spectral properties of both data sets:

$$MLT_{i,j,k} = \sqrt{a \times b \times Pan_{i,j} \times MS_{i,j,k}}$$

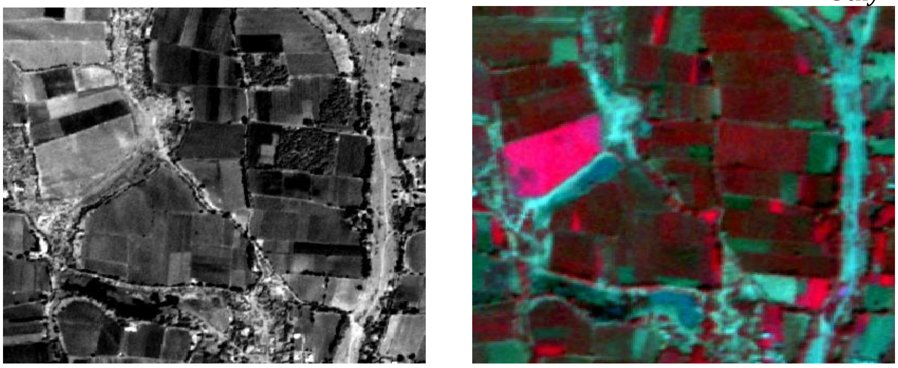


Figure 1: (a) PAN Image from CARTOSAT (b) Multispectral Image from LISS-IV

- Where MLT is the output image and i and j are pixels of band k. Pan and MS are the panchromatic data and multi-spectral data respectively. To compensate for this effect, weighting coefficients a and b can be used. However arbitrary, the weights used for the panchromatic and infrared channels increase the spatial resolution from 20 to 10 m and preserve much of the infrared information.

B. *Modified Brovey (MB)*

- Since the original Brovey Transform can only allow three bands to be fused, the transform has to be modified. The Modified Brovey algorithm is a ratio method where the data values of each band of the MS data set are divided by the sum of the MS data set and then multiplied by the Pan data set. The MB algorithm attempts to maintain the spectral integrity of each band by incorporating the proportionate value of each band as related to the MS data set before merging it with the Pan data set. By adjusting for the effects of the Pan data set's spectral properties when combining the data sets, the spectral quality of the MS data set is mainly preserved:

$$MB_{i,j,k} = 2 \times (MS_{i,j,k} / \sum MS_{i,j,1,n}) \times Pan_{i,j}$$

- Where MB is the output image and i and j are pixels of band k. Pan and MS are the panchromatic data and multi-spectral data respectively.

C. *High Pass Filter (HPF)*

- The High-Pass Filter model was first introduced as a method to reduce data quantity and increase spatial resolution potential for Landsat MSS data. Then it was extended to more diverse multi-spatial data sets when Thematic Mapper (TM) data was merged with a digitized National High Altitude Program (NHAP) aerial photograph. The HPF method submits the high spatial resolution imagery to a small convolution mask (3 x 3) which acts upon the high-frequency spatial information, effectively reducing the lower frequency spectral information of the high spatial resolution image. The filtered result is then added to the MS data and the result divided by two to offset the increase in brightness values:

$$HPF_{i,j,k} = (MS_{i,j,k} + FP_{i,j}) / 2$$

- Where HPF is the output image and i and j are pixels of band k. FP is the filtered result of High-Pass Filter, This technique preserves the MS data while incorporating the spatial resolution of the PN data.

D. *IHS*

- The IHS technique is one of the most commonly used fusion techniques for sharpening. It has become a standard procedure in image analysis for color enhancement, feature enhancement, improvement of spatial resolution and the fusion of disparate data sets.
- In the IHS space, spectral information is mostly reflected on the hue and the saturation. From the visual system, one can conclude that the intensity change has little effect on the spectral information and is easy to deal with. So, intensity plane of MS image is replaced by PAN image and then it is transformed back into RGB Color Space. Different transformation matrixes (TM) are used for converting an image from RGB space to IHS space and vice-a-versa. Here, 4 transformation matrixes are used for the study.

E. *Principal Component Analysis (PCA)*

- The principal component (PC) transform is a statistical technique that transforms a multivariate dataset of correlated variables into a dataset of uncorrelated linear combinations of the original variables. For images, it creates an uncorrelated feature space that can be used for further analysis instead of the original multispectral feature space. The PC is applied to the multispectral bands. The panchromatic image is histogram matched to the first principal component (sometimes to the second). It then replaces the selected component and an inverse PC transform takes the fused dataset back into the original multispectral feature space. The advantage of the PC fusion is that the number of bands is not restricted (such as for the original IHS or Brovey fusions).

- It is, however, a statistical procedure which means that it is sensitive to the area to be sharpened. The fusion results may vary depending on the selected image subsets.

F. Local Means Matching (LMM)

$$F_{k(i,j)} = P_{(i,j)} \times \frac{\bar{M}_{k(i,j)(w,h)}}{\bar{P}_{(i,j)(w,h)}}$$

- It is a statistical technique, where $F_k(i,j)$ is the fused image, P(i,j) and $M_k(i,j)$ are respectively the high and low spatial resolution images at pixel coordinates (i,j); $M_{k(bar)}(i,j)(w,h)$ and $P_{(bar)}(i,j)(w,h)$are the local means calculated inside the window of size (w,h).

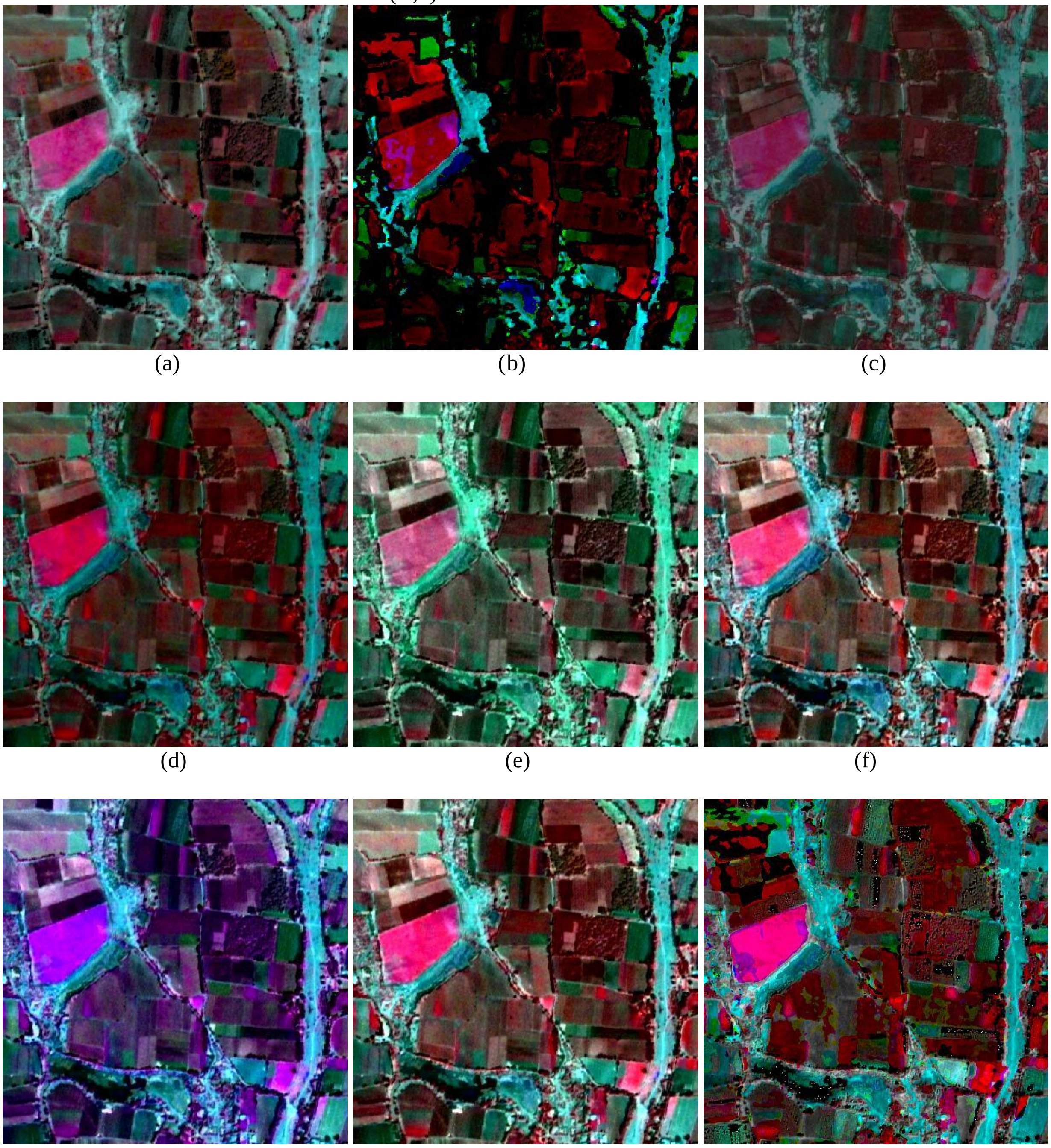


Figure 2: Fused Images produced from Different Algorithms (a) MLT (b) MB (c) HPF (d) IHS TM-1 (e) IHS TM-2 (f) IHS TM-3 (g) IHS TM-4 (h) PCA (i) LMM

III. PERFORMANCE EVALUATION

To evaluate the ability of enhancing spatial details and preserving spectral information of Image Fusion Algorithms, some Indices including Entropy (En), Correlation Coefficient (CC), Signal-to Noise Ratio (SNR), Normalization Root Mean Square Error (NRMSE) of the image are used. These measures are described below.

A. Entropy (En)

Entropy is a measure to directly conclude the performance of image fusion. The Entropy can show the average information included in the image and reflect the detail information of the fused image. Commonly, the greater the Entropy of the fused image is, the more abundant information included in it, and the greater the quality of the fusion is. According to the information theory of Shannon, The Entropy of image is:

$$E = -\sum_{i=0}^{255} P_i \log_2 P_i$$

Where E is the Entropy of image, and is the probability of i in the image.

B. Correlational Coefficient (CC)

CC measures the correlation between the original and the fused images. The higher the correlation between the fused and the original images, the better the estimation of the spectral values. The ideal value of correlation coefficient is 1.

$$CC = \frac{\sum_i^n \sum_j^m (F_k(i,j) - \overline{F}_k)(M_k(i,j) - \overline{M}_k)}{\sqrt{\sum_i^n \sum_j^m (F_k(i,j) - \overline{F}_k)^2} \sqrt{\sum_i^n \sum_j^m (M_k(i,j) - \overline{M}_k)^2}}$$

Where CC is the Correlation Coefficient, F is the fused image and i and j are pixels, MS is the multi-spectral data.

C. Signal-to-Noise Ratio (SNR)

Signal-to-noise ratio is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. While SNR is commonly quoted for electrical signals, it can be applied to any form of signal. For, images it is defined as:

$$SNR_k = \sqrt{\frac{\sum_i^n \sum_j^m (F_k(i,j))^2}{\sum_i^n \sum_j^m (F_k(i,j) - M_k(i,j))^2}}$$

D. Normalized Root Mean Square Error (NRMSE)

A commonly used reference-based assessment metric is the root mean square error (RMSE) which is defined as follows:

$$RMSE = \sqrt{\frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} (R(m,n) - F(m,n))^2}$$

Where R(m,n) and F(m,n) are reference and fused images, respectively, and M and N are image dimensions.

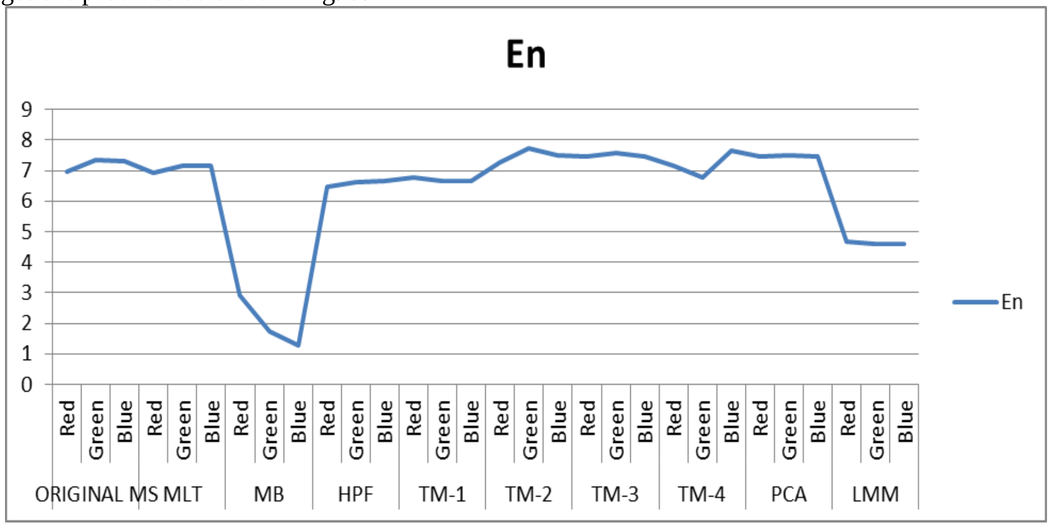
These measures of the fused images produced above by different algorithms are given in the table below.

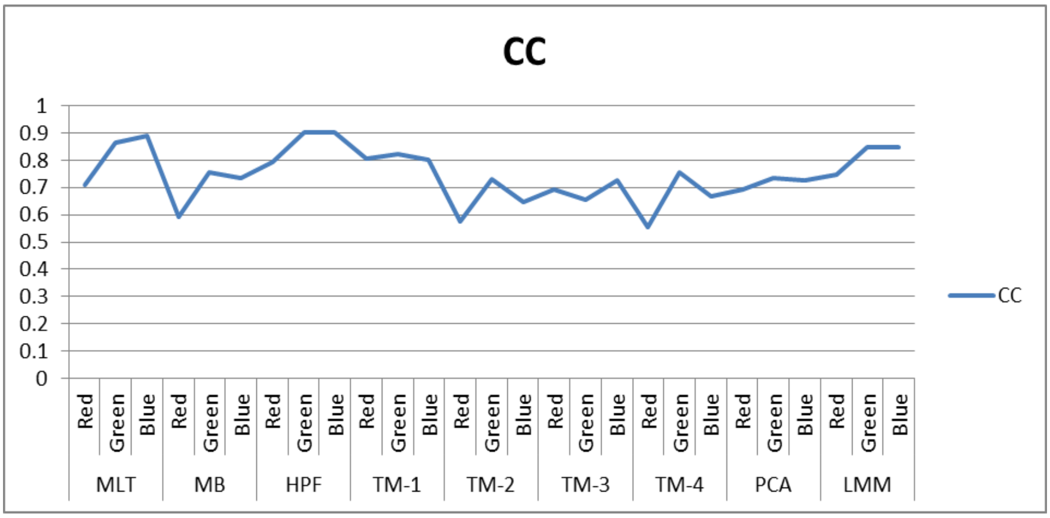
TABLE I: PERFORMANCE EVALUATION INDICES

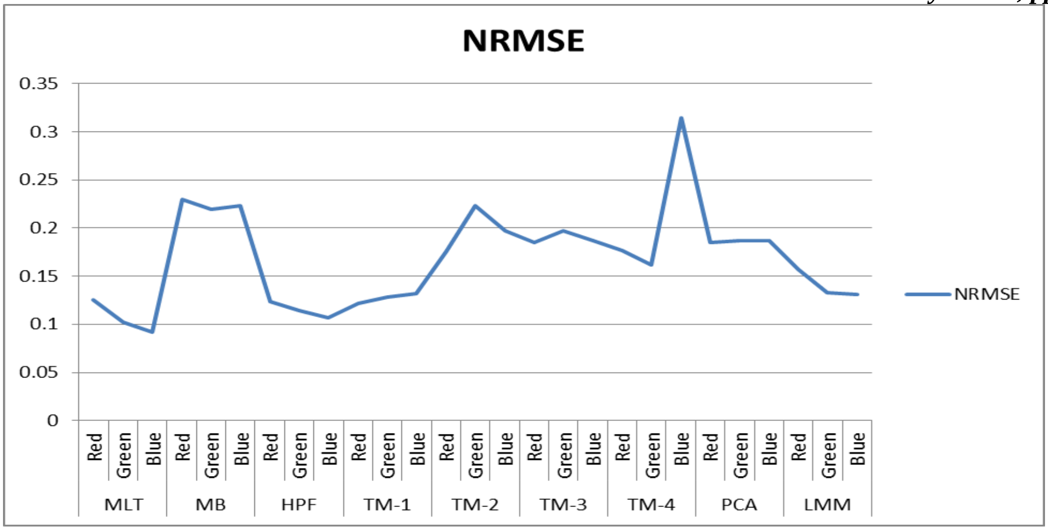
Method	***Band***	***En***	***CC***	***NRMSE***	***SNR***
ORIGINAL MS	Red	6.9535			
	Green	7.3532			
	Blue	7.3034			
MLT	Red	6.9159	0.7086	0.1251	2.4721
	Green	7.1405	0.8637	0.1026	3.094
	Blue	7.1544	0.8879	0.092	3.4645
MB	Red	2.9164	0.5927	0.23	0.8938
	Green	1.7163	0.7569	0.2194	0.9809
	Blue	1.2674	0.7339	0.2231	0.9174
HPF	Red	6.4527	0.7923	0.1235	1.9052
	Green	6.6268	0.9009	0.1144	2.0757
	Blue	6.6479	0.9017	0.107	2.1871
TM-1	Red	6.7822	0.8074	0.1221	2.2932

	Green	6.6756	0.8224	0.1281	2.0089
	Blue	6.6669	0.8001	0.1316	1.842
TM-2	Red	7.2871	0.5775	0.1758	1.9645
	Green	7.7255	0.7285	0.2228	2.0802
	Blue	7.5113	0.6487	0.1972	2.0005
TM-3	Red	7.4569	0.6941	0.1845	2.2634
	Green	7.5557	0.6535	0.1973	2.0242
	Blue	7.4542	0.7245	0.1868	2.1506
TM-4	Red	7.1713	0.5563	0.1762	1.8575
	Green	6.7735	0.7543	0.1619	2.1847
	Blue	7.6541	0.6657	0.314	1.7605
PCA	Red	7.4569	0.6941	0.1845	2.2634
	Green	7.5066	0.7355	0.1868	2.1987
	Blue	7.4542	0.7245	0.1868	2.1506
LMM	Red	4.6724	0.7479	0.1575	2.1374
	Green	4.5844	0.8465	0.1328	2.5298
	Blue	4.6002	0.8482	0.1308	2.5531

To simplify the comparison of the different fusion methods, the values of the En, CC, SNR, NRMSE index of the Fused images are provided as chart in Fig. 3.







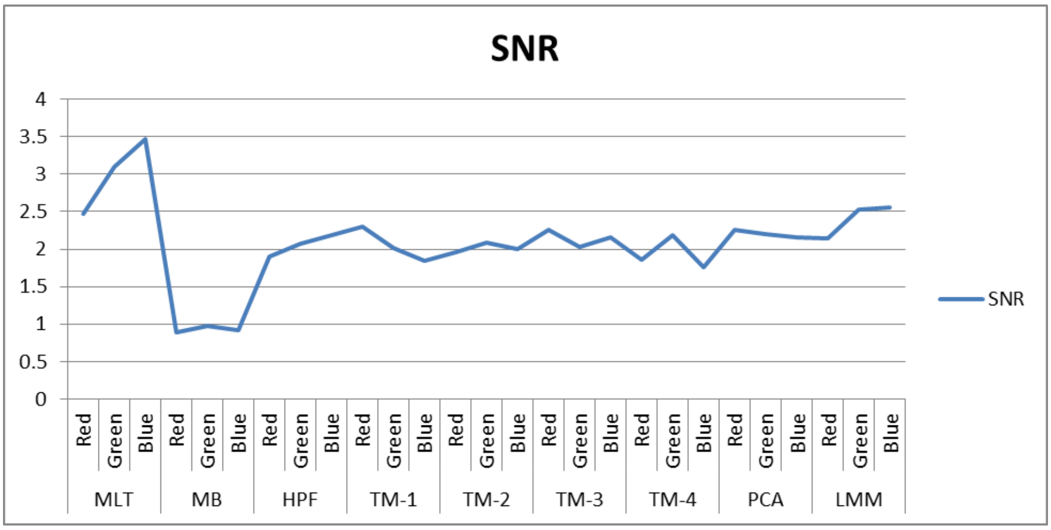


Figure 3: Chart Representation of En, CC, NRMSE, SNR

IV. Results

First of all, if we compare the outputs of all algorithms visually, we can see that PCA and TM-3 shows best results. TM-1 and MLT are slightly less good than that. In, TM-2 and TM-4 we can see that spectral information has changed up to some extent, while it is completely distorted in MB and LMM.

From Entropy plot, we can see clearly that it is too low for MB and LMM compared to other techniques, which means that these techniques produce outputs with less information and visual distortion, which supports our visual observation. For other algorithms, it is almost constant. Correlational Coefficient also seems more or less constant and up to its maximum possible value for all the methods. Signal-to-Noise Ratio is almost constant except for MLT and MB. Normalized Root Mean Square Error plot has crest at three points; at MB, at Green band of TM-2 and at Blue band of TM-4. For, MB the reason is same as above. For TM-2 and TM-4, from CC plot it can be observed that there is trough at Red band of both. From these two facts, we can conclude that TM-2 should have more of a Greenish shade and TM-4 should have more of a Bluish shade, which we can see easily from their output images. So, after qualitative and quantitative comparison, we can see that TM-3, PCA, TM-1, MLT are better methods for fusion compared to others.

V. Conclusions

The aim of this paper is to study the Image Fusion techniques used in remote sensing including Multiplication, Modified Brovey, High Pass Filter, IHS, Principal Component Analysis & Local Means Matching and apply them on the dataset, consisting of PAN image from CARTOAST-I and MS image from LISS-IV (ResourceSat). The results are evaluated qualitatively and quantitatively using various indices including En, CC, NRMSE and SNR. Based on it, best methods are identified for the fusion of the given dataset.

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