An Efficient Pan-Sharpening Method via a Combined Adaptive PCA Approach and Contourlets

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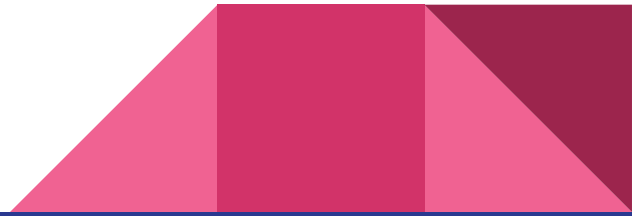
Introduction

Pan-Sharpening with Adaptive PCA and Contourlet Transform is a study aimed at enhancing pan-sharpening techniques. This involves a strategic merger of Adaptive Principal Component Analysis (PCA) and the Contourlet Transform, combining the strengths of spectral preservation and spatial transformation.



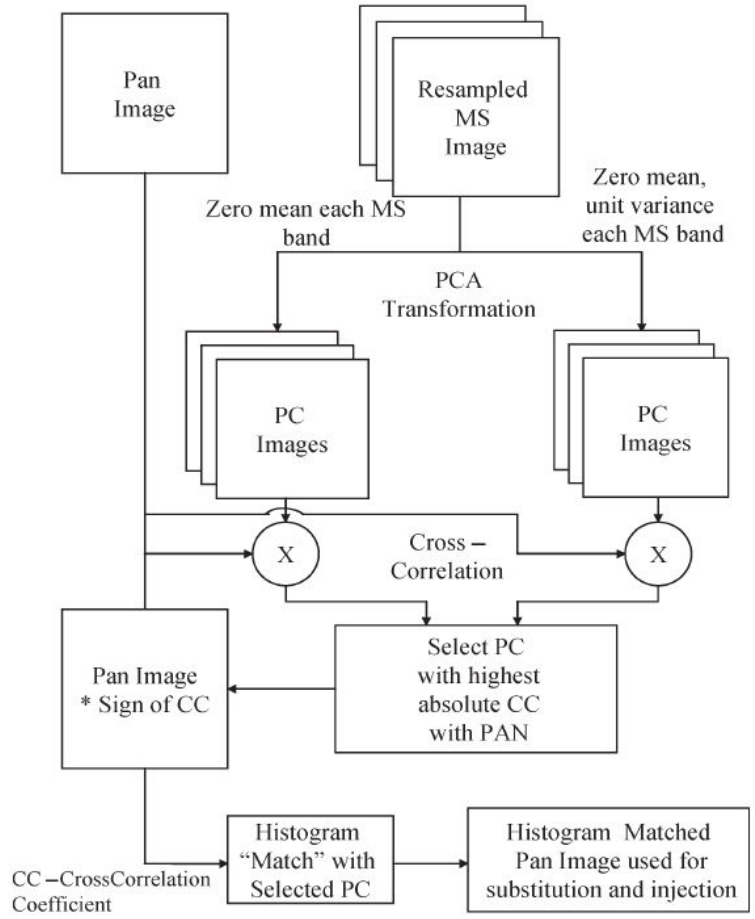


Fig. 1. Adaptive selection of PC for substitution and injection.

TABLE III
DATASETS' STATISTICS

Image Set	PC	Zero mean MS bands		Standardardize(Std) MS band by zero mean and unit variance	
		Variances (%)	CC with Pan	Variances (%)	CC with Pan
ik1	First	80.666	0.813	79.401	**0.818**
	Second	18.558	0.238	19.685	0.221
	Third	0.681	0.001	0.829	-0.015
	Fourth	0.094	-0.021	0.084	-0.020
ik2	First	69.754	**-0.714**	75.211	-0.687
	Second	29.718	-0.382	24.152	-0.429
	Third	0.492	0.008	0.597	0.016
	Fourth	0.036	-0.001	0.040	0.000
ik3	First	85.610	-0.797	76.309	-0.091
	Second	13.898	-0.441	21.096	**-0.904**
	Third	0.416	0.010	2.097	0.069
	Fourth	0.076	0.037	0.498	0.009
qb1	First	60.393	**0.666**	74.245	0.541
	Second	39.152	-0.310	24.840	0.496
	Third	0.397	-0.036	0.751	-0.055
	Fourth	0.057	-0.006	0.164	0.000
qb2	First	53.383	0.324	73.768	0.512
	Second	45.952	**-0.677**	25.097	-0.547
	Third	0.611	-0.048	1.047	-0.070
	Fourth	0.055	-0.005	0.088	-0.003
ld1	First	74.754	0.800	71.635	**0.836**
	Second	24.127	0.496	27.039	0.434
	Third	1.119	-0.029	1.326	0.002
ld2	First	87.271	-0.717	67.185	**-0.779**
	Second	12.227	0.537	32.315	0.442
	Third	0.502	-0.021	0.500	-0.001

Methodology Overview

The methodology involves Adaptive PCA, which preserves spectral information, and the Contourlet Transform, known for efficient spatial transformation. By combining these methods, the study seeks to achieve more effective and balanced pan-sharpening results.

Nonsubsampled Contourlet Transform (NSCT)

The Nonsubsampled Contourlet Transform (NSCT) is employed in the pan-sharpening process to provide directional information. With computational complexity comparable to Nonsubsampled filter banks (NSFB), the nonsubsampled approach is particularly emphasized for enhanced effectiveness.

1. 2D Nonsubsampled Contourlet Transform (NSCT):

The 2D Nonsubsampled Contourlet Transform of an image $f(x, y)$ is represented as $C(f)$, where C denotes the Contourlet Transform.

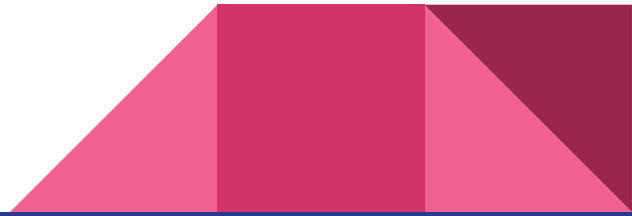
$$C(f) = \{C_b^d(f) : b = 1, \ldots, B, d = 1, \ldots, D_b\}$$

Here,

- B is the number of scales.
- D_b is the number of directions at scale b.
- $C_b^d(f)$ represents the coefficients at scale b and direction d.

Improved Adaptive PCA–Contourlet Merger

The pan-sharpening process begins with coregistering the MultiSpectral (MS) and PANchromatic (PAN) images. Adaptive PCA is applied for Principal Component (PC) selection, followed by histogram matching and Contourlet Transform spatial transformations. The study replaces only the detail contourlet coefficients of the selected PC image.



Experimental Datasets

Evaluation is conducted using datasets from IKONOS, QuickBird, and Landsat-7 ETM+ satellites. These datasets are radiometrically calibrated and orthorectified, with distinct characteristics summarized in tables for spectral bands, resolution, and other parameters.

Note- Orthorectification is a process in remote sensing that corrects geometric distortions in satellite or aerial imagery caused by terrain relief and sensor geometry. It produces georeferenced images, ensuring accurate spatial information for applications like mapping and environmental monitoring.

TABLE I
SATELLITE DATASETS CHARACTERISTICS

Features	Imagery Type		
	IKONOS	QUICKBIRD	LANDSAT 7 ETM+
MS Image – Spectral Bands and Range	Blue (445-516 nm), Green (506-595 nm), Red (632-698 nm), NIR (757-853 nm)	Blue (450-520 nm), Green (520-600 nm), Red (630-690 nm), NIR (760-900 nm)	Blue (450-515 nm), Green (525-605 nm), Red (630-690 nm), NIR (760-900 nm), Mid IR (1550-1750 nm), Mid IR (2080-2350 nm).
Pan Image – Spectral Range	450-900 nm	450-900 nm	520-920 nm
Spatial Resolution MS Image	4 m	2.4 m	28.5 m
Spatial Resolution Pan Image	1 m	0.6 m	14.25 m
Resolution Ratio of MS and Pan Image	4	4	2
Radiometric Resolution	11	11	8

Results - Adaptive PCA vs. Standard PCA

The study compares Adaptive PCA with Standard PCA through global quality indexes. Visual comparisons and quantitative metrics reveal the significant improvement in pan-sharpened images using the Adaptive PCA approach, especially in datasets with low correlation.

Results - Contourlet vs. Wavelet

A comparison is made between the PCA–contourlet and PCA–wavelet methods. The nonsubsampled contourlet approach consistently outperforms wavelets, as confirmed by statistical tests, emphasizing the superior spatial transformation capabilities of contourlets.

Results - Adaptive PCA–Contourlet Merger

Pan-sharpening using the Adaptive Principal Component Analysis –Nonsubsampled Contourlet Transform merger (APCA–NSCT) is highlighted, showcasing visual and quantitative improvements over Principal Component Analysis–Nonsubsampled Contourlet Transform (PCA–NSCT) and Adaptive Principal Component Analysis–Redundant Discrete Wavelet Transform (APCA–RDWT). The method proves particularly effective in preserving spectral information.

Evaluation Indexes

ERGAS (Enhanced Spatial-Resolution by Generalized Approach to Imaging Spectrometer): Measures average relative error between the original high-resolution image and the pan-sharpened image.

RASE (%): Relative Average Spectral Error computes the average spectral distortion as a percentage between pan-sharpened and original images.

SAM (Spectral Angle Mapper): Quantifies spectral similarity based on the angle between spectral vectors of corresponding pixels.

SID (Structure Intensity Deviation): Evaluates structural deviation in spatial information between pan-sharpened and reference images.

Qavg (Quality Index): Represents an overall quality measure combining spectral and spatial characteristics in pan-sharpening.

Conclusion and Future Work

The study concludes with a summary of key findings, emphasizing the effectiveness of the Adaptive PCA–Contourlet merger. Future work is suggested, especially in exploring optimal filter selections for contourlet and wavelet transforms.