

Novel K-Means Clustering Approach for Compressing Hyperspectral Image

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ABSTRACT

The hyperspectral imagery can be very large, with a single image potentially occupying hundreds of mega bytes making acquisition, storage and transmission increasing complexity. This paper is proposed to compress the hyperspectral image by using k-means clustering. The compression ratio is improved by using k-means clustering approach by clustering pixels into classes based on pixel spectral similarity with other class members. Reconstruction quality is measured with a signal to noise ratio (SNR) in decibels, peak signal to noise ratio (PSNR) in decibels, mean-square error (MSE) and compression ratio (CR). The performance of the proposed approach is compared with PCA and DWT. Experimental result demonstrates that Novel k-means provide 90% compression ratio and 1.22 bit per pixel (bpp) of the original image.

Keywords : Hyperspectral image, Kmeans, SNR, PSNR, MSE and CR.

1 INTRODUCTION

Hyperspectral imaging amounts to collecting the energy reflected or emitted by ground targets at a typically very high number of wavelengths, resulting in a data cube containing tens to hundreds of bands. These data have become increasingly popular, since they enable plenty of new applications, including detection and identification of surface, and atmospheric constituents, analysis of soil type, agriculture and forest monitoring, environmental studies, and military surveillance. The data are usually acquired by a remote platform (a satellite or an aircraft), and then downlinked to a ground station. Due to the huge size of the datasets, compression is necessary to match the available transmission bandwidth.

Although there have been a number of approaches to the compression of hyperspectral imagery proposed in recent years prominent techniques would include vector quantization (VQ) or principal component analysis (PCA) applied to spectral pixel vectors, as well as 3D extensions of common image-compression methods such as the discrete cosine transform (DCT) most of the approaches as proposed are not particularly well-suited to the image-transmission task. That is, in many applications involving the communication of images, progressive transmission is desired in that successive reconstructions of the image are possible. Thus the receiver can produce a low-quality representation of the image after having received only a small portion of the transmitted bitstream, and this "preview" representation can be successively refined in quality as more and more of the bitstream is received.

In many hyperspectral compression techniques, such as progressive transmission is not supported, and, if the bitstream is not received in its entirety, no dataset can be reconstructed. In this case, the bits that are received are generally useless in the application. It is anticipated that progressive-transmission capabilities will be of increasing interest, particularly for hy-

perspectral applications involving satellite-to-ground communications which are inherently susceptible to transmission failure due to high noise levels and limited bandwidth.

The performance of JPEG 2000 with principal component analysis (PCA) in terms of information preservation superior to that of discrete wavelet transform (DWT) [1], [2], [3], [4]. PCA provide dimensionality reduction in addition to spectral decorrelation and JPEG 2000 provides spatial coding of PC images. The performance is further improved by retaining and coding small subset of PCs rather than entire PCs [3].

A pioneering work on seed initialization was proposed by Ball and Hall (BH). This method is sensitive to the parameter and the order of the inputs [5].

Astrahan [6] suggested a method using two distance parameters, d_1 and d_2 which first computes the density of each point in the dataset. The highest density point is chosen as the first seed and subsequent seed points are chosen in the order of decreasing density subject to the condition that each new seed point be at least at a distance of d_2 from all other previously chosen seed points. The drawback in this approach is that it is very sensitive to the values d_1 and d_2 and requires hierarchical clustering.

Bradley and Fayyad (BF) [7] proposed an initialization method that is suitable for large datasets. The main idea of their algorithm is to select "m" subsamples from the dataset, apply the k-means on each subsample independently, keep the final k centers from each subsample and produce a set that contains m_k points. They apply the k-means on this set m times: for the first time, the first k points as initial centers and for the second time, the second k points and so on. And the algorithm returns the best k centers from this set. They use 10 subsamples from the data set, each of size 1% of the full dataset size.

Finally, a last round of k-means is performed on this dataset and the cluster centers of this round are returned as the initial seeds for the entire dataset. This method generally performs better than k-means and converges to the local optimum faster. However, it still depends on the random choice of the subsamples and hence, can lead to poor clustering in an unlucky session.

In this paper we propose a Novel K-means approach for hyperspectral image compression where seed selection for edge blocks (high variant blocks) and non-edge blocks (low variant blocks).

The rest of paper is organized as follows: section 2 briefly describe various compression methods for hyperspectral image, section 3 presents proposed compression method, section 4 presents the performance analysis of the proposed method and section 5 concludes our work.

2 COMPRESSION TECHNIQUES

PCA, a well-known technique in multivariate data analysis, has been widely used in the hyperspectral setting for spectral decorrelation as well as spectral dimensionality reduction. Capable of optimal decorrelation in a statistical sense, PCA often provides excellent decorrelation in practice.

When all PCs are retained, PCA is commonly known as the Karhunen-Loève transform (KLT), in which case a hyperspectral image with N spectral bands produces an $N \times N$ unitary KLT transform matrix. As this matrix is data dependent, it must be communicated to the decoder in any KLT-based compression system. Alternatively, PCA can effectuate dimensionality reduction by retaining in the KLT transform matrix only those eigenvectors corresponding to the P largest eigenvalues. The data volume passed to the encoder then has $P < N$, rather than N , spectral components, and the resulting $N \times P$ PCA matrix is communicated to the decoder[3].

The technique of PCA has found wide use in digital processing of hyperspectral images. PCA and image fusion techniques are often used to enhance an image particularly in the land-cover classification of satellite images, where such images are used for increasing the interpretability of human observer and for improving the accuracy of the classification.

A 2D discrete wavelet transform (DWT) can be implemented as a filter bank as illustrated in Fig. 1. This filter bank decomposes the original image into horizontal (H), vertical (V), diagonal (D), and baseband (B) subbands, each being one-fourth the size of the original image. Wavelet theory provides filter-design methods such that the filter bank is perfectly reconstructing (i.e., there exists a reconstruction filter bank that will generate exactly the original image from the decomposed subbands H, V, D, and B), and such that the lowpass and highpass filters have finite impulse responses (which aids practical implementation). Multiple stages of decomposition can be cascaded together by recursively decomposing the baseband; the subbands in this case are usually arranged in a pyramidal form as illustrated in Fig.2.

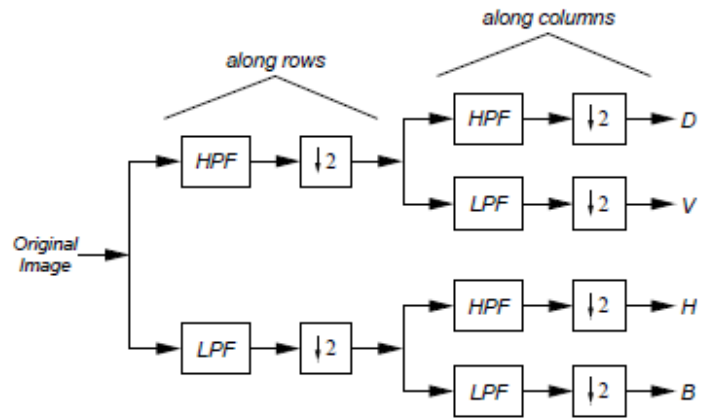


Fig.1. One stage of 2D DWT decomposition composed of lowpass (LPF) and highpass (HPF) filters applied to the columns and rows independently.

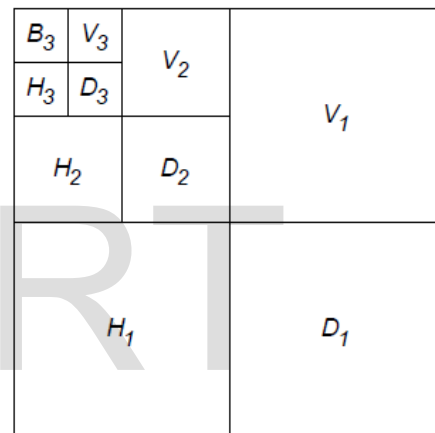


Fig.2. A 3-scale, 2D DWT pyramid arrangement of subbands.

The k-means algorithm is an algorithm to cluster objects based on attributes into k partitions. The objective is to minimize total intra-cluster variance, or the squared error function.

$$V = \sum_{i=1}^k \sum_{X_j \in S_i} |X_j - \mu_i|^2 \quad (1)$$

where there are k clusters S_i , $i = 1, 2, \dots, k$ and μ_i is the centroid or mean point of all the points in cluster S_i . The algorithm starts by partitioning the input points into k initial sets, either at random or using some heuristic data. It then calculates the centroid of each set and constructs a new partition by associating each point with the closest centroid.

Then the centroids of each set are recalculated and the algorithm is repeated by alternate application of these two steps until convergence, which is obtained when the points no longer switch clusters (or alternatively centroids are no longer changed).

Despite its efficiency, it has drawbacks like apriori fixation of number of clusters and random selection of initial seeds. Inappropriate choice of initial seeds may yield poor results and leads to increase in computation time for convergence.

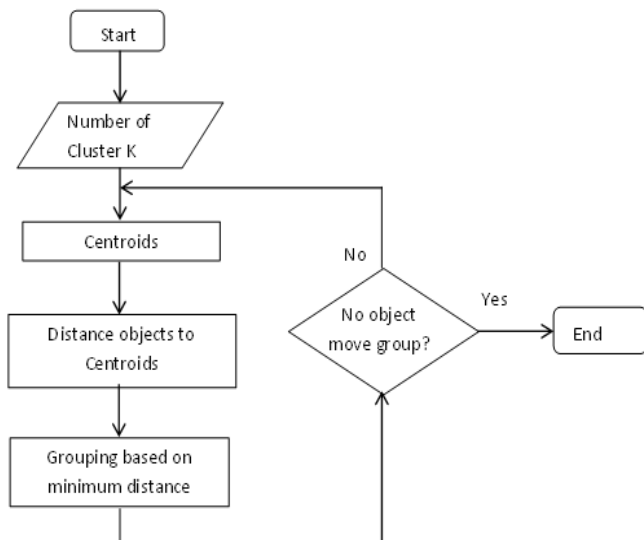


Fig.3. Kmeans Flowchart

3 NOVEL KMEANS

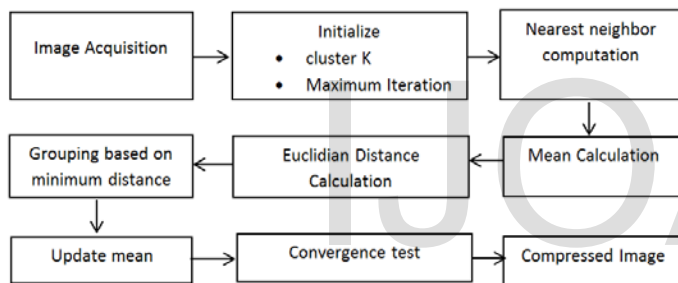


Fig.3. Block Diagram of Novel Kmeans

The proposed method is an innovative approach to enhance the performance of K-means algorithm. It adopts divide and conquer strategy by dividing the input dataspace into classes and apply K-means clustering. Novel K-means segments input image into K clusters and works into two phases as follows. In the first phase, the input vectors are divided into N classes based on the mean value of each vector. A training vector is assigned to a class C_1 , if its mean value is less than or equal to the domain of C_1 . This mean based grouping of input data speeds up convergence resulting in reduction of computation time.

K-Means algorithm is performed on each class of vectors with initial seeds. The number of initial seeds M in each class is proportional to its size. The initial seeds are selected with the right blend of statistical features (mean, no of pixels clustered around mean and mode parameter) of the class population.

The hyperspectral dataset used, was generated by the SAMSON sensor. It covers the spectral range of 400nm-900nm with a band width of 3.2nm. The data was collected by the Florida Environmental Research Institute as part of the GOES-R sponsored experiment. The image size is 952 X 952 X 156.

3.1 Proposed Algorithm

The hyperspectral image is divided into 4x4 vectors and the number of classes N should be set before the seed selection and pruning phases. The choice of N plays a crucial role in the performance of Novel K-means.

3.1.1 Centroid selection phase

1. Load hyperspectral image.
2. Initialize the dimension k.
3. Initialize max_iterations.
4. Initialize means to randomly selected colors of hyperspectral image.
5. Calculate the nearest neighbor for every pixel in image.
6. Calculate the means for every iteration as max_iterations.
7. Find number of pixels clustered around nth mean.
8. For every pixel in the image, calculate the nearest mean.
9. Update the mean with new mean.
10. For i=1 to row
For j=1 to column
 - Calculate the nearest mean for the pixels in the image
 - Assign every pixel value's corresponding r, g and b values.
 - Find the difference between r,g,b values with mean value.
 - Find the euclidean distance.
 - Find minimum euclidean distance
 - Assign minimum euclidean distance as nearest mean.
 - Add the pixel to rgb values of its nearest mean.
11. End
12. End
13. Calculate the new means for no of dimensions.
 - If pixels are assigned
 - Update the mean
 - End.
14. Convergence Test
15. Find how much means values are changing

$$d = \sum_{i=1, j=1}^N \sqrt{(new\ mean(i, j))^2 - (mean(i, j))^2}$$
 Where $i \neq j$
16. Update means with new-means

3.1.2 Reconstruction of image

17. Calculate the euclidean distance between each of newly generated image and vectors in partial code book constructed.
18. Add only those vectors whose euclidean distance is minimum to codebook.
19. Repeat the processes for dimensions
20. Final code book resulting after step 19 is the initial code book for entire set.
21. Save Image

4 RESULTS AND DISCUSSION

The software implementation of the algorithm is written in a Matlab environment using Matlab 7.10 software. The hyper-spectral dataset used is generated by the SAMSON sensor. It covers the spectral range of 400nm-900nm with a bandwidth of 3.2nm. The data was collected by the Florida Environmental Research Institute as part of the GOES-R sponsored experiment.

The instrument flown during the collect is the SAMSON, a push-broom, visible to near IR, hyperspectral sensor. This sensor was designed and developed by FERI [9]. They have 156 contiguous bands and 952X952 pixel resolution.

In this paper it was decided to measure the performance with the following performance measures:

Peak signal-to-noise ratio (PSNR): This is a commonly used quantitative fidelity criteria (in image processing applications). Let X_i be the original pixel in spatial position of the spectral band b (of size $N \times M$) and X_i the respective reconstructed pixel, then for each spectral band $1 \leq b \leq 156$, PSNR_b is defined by

$$PSNR_b = 10 \log_{10} \frac{MAX_i^2}{MSE} \tag{2}$$

Where MAX_i is the maximum possible pixel value of the image and MSE is the mean-square error measuring the deviation of the reconstructed image from the original image. MSE is defined by

$$MSE = \frac{1}{NM} \sum_{x=1}^N \sum_{y=1}^M [X_i - X_i]^2 \tag{3}$$

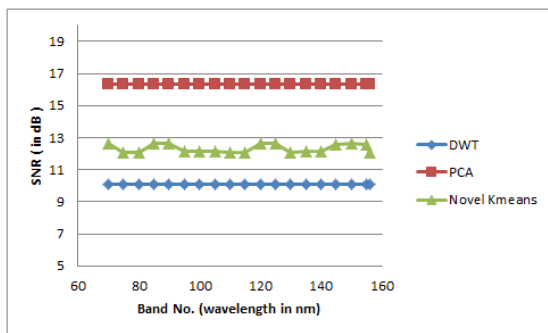
An average PSNR is obtained as the quality measure, where the averaging is performed over B spectral bands:

$$\overline{PSNR} = \frac{1}{B} \sum_{b=1}^B PSNR_b \tag{4}$$

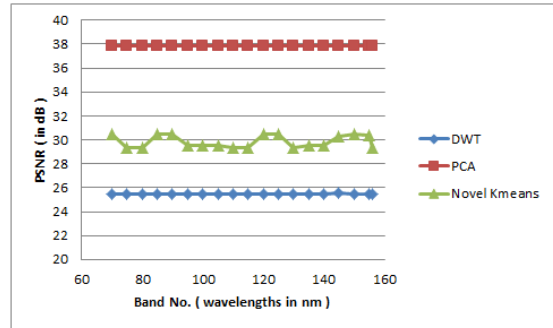
(B= 156 in our image)

Signal to noise ratio (SNR) in decibels, defined as the log ratio between the variance of the original data and the variance of the error.

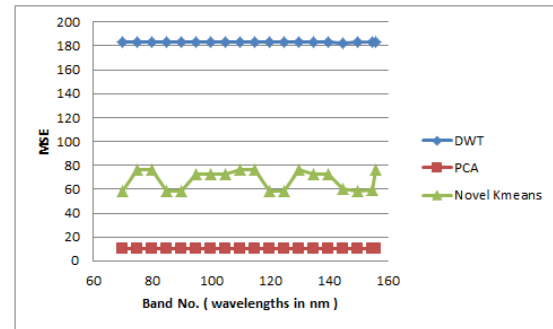
Experimental results demonstrate that Novel Kmeans shows optimal performance interms of SNR, PSNR, MSE and Compression ratio. PSNR for DWT, PCA and Kmeans is 25.51dB, 37.84dB and 29.85 dB respectively. Compression ratio for kmeans is 90% which is higher than PCA (i.e 79.72%) and DWT (51.65%). Bit per pixel (BPP) is smallest for kmeans than PCA and DWT as shown in table 4.



(a)SNR of hyperspectral image at different wavelengths



(b)PSNR of hyperspectral image at different wavelengths



(c) MSE of hyperspectral image at different wavelengths

Fig.3. SNR, PSNR and MSE at different wavelength (400nm to 900nm)

Table 1:
SNR of hyperspectral image at different wavelengths

Band No.	SNR (in dB)		
	DWT	PCA	Novel Kmeans
69	10.0853	16.3288	12.3942
70	10.0869	16.3288	12.6384
75	10.0937	16.3288	12.0553
80	10.0937	16.3288	12.0553
85	10.0869	16.3288	12.6384
90	10.0869	16.3288	12.6384
95	10.0908	16.3288	12.1537
100	10.0908	16.3288	12.1537
105	10.0926	16.3288	12.1524
110	10.0937	16.3288	12.0553
115	10.0937	16.3288	12.0553
120	10.0869	16.3288	12.6384
125	10.0869	16.3288	12.6384
130	10.0937	16.3288	12.0553
135	10.0908	16.3288	12.1537

140	10.0926	16.3288	12.1524
145	10.0972	16.3288	12.5635
150	10.0869	16.3288	12.6384
155	10.0902	16.3288	12.5905
156	10.0937	16.3288	12.0553

Table 2:

PSNR of hyperspectral image at different wavelengths

Band No.	PSNR (in dB)		
	DWT	PCA	Novel Kmeans
69	25.4956	37.8425	29.9974
70	25.4983	37.8425	30.4565
75	25.5109	37.8425	29.3255
80	25.5109	37.8425	29.3255
85	25.4983	37.8425	30.4565
90	25.4983	37.8425	30.4565
95	25.5054	37.8425	29.5226
100	25.5054	37.8425	29.5226
105	25.5091	37.8425	29.5155
110	25.5109	37.8425	29.3255
115	25.5109	37.8425	29.3255
120	25.4983	37.8425	30.4565
125	25.4983	37.8425	30.4565
130	25.5109	37.8425	29.3255
135	25.5054	37.8425	29.5226
140	25.5091	37.8425	29.5155
145	25.5173	37.8425	30.3189
150	25.4983	37.8425	30.4565
155	25.505	37.8425	30.3683
156	25.5109	37.8425	29.3255

Table 3:

MSE of hyperspectral image at different wavelengths

Band No.	MSE		
	DWT	PCA	Novel Kmeans
69	183.453	10.6864	65.0645
70	183.3377	10.6864	58.5374
75	182.808	10.6864	75.9497
80	182.808	10.6864	75.9497
85	183.3377	10.6864	58.5374
90	183.3377	10.6864	58.5374
95	183.0385	10.6864	72.5812
100	183.0385	10.6864	72.5812
105	182.8812	10.6864	72.6994
110	182.808	10.6864	75.9497
115	182.808	10.6864	75.9497
120	183.3377	10.6864	58.5374
125	183.3377	10.6864	58.5374
130	182.808	10.6864	75.9497
135	183.0385	10.6864	72.5812
140	182.8812	10.6864	72.6994
145	182.5387	10.6864	60.4213
150	183.3377	10.6864	58.5374
155	183.0554	10.6864	59.7373
156	182.808	10.6864	75.9497

Table 4:

Compression Ratio and BPP

	Compression Ratio	BPP
DWT	51.65%	6.05
PCA	79.72%	2.54
Novel Kmeans	90.25%	1.22

4 CONCLUSION

In this paper, we have proposed a Novel kmeans clustering approach for hyperspectral image compression where selection of initial centroids depends on the statistical features of hyperspectral image (mean, no of pixels clustered around mean and mode parameter).

The Novel Kmeans Clustering examined using SAMSON hy-

perspectal sample data. The performance of these algorithms is evaluated based on PSNR of the compressed image, compression ratio, BPP and compared with DWT and PCA. For Novel Kmeans PSNR = 29.85 dB, CR = 90%, BPP = 1.22, for PCA PSNR = 37.84 dB, CR = 79.72%, BPP = 2.54 and for DWT PSNR = 25.51 dB, CR = 51.65%, BPP = 6.05.

When band number changes its give variable results in terms of MSE, SNR and PSNR. Experimental results reveled that Novel Kmeans outperforms PCA and DWT in terms of compression ratio, bit per pixel (bpp).

ACKNOWLEDGMENT

I would like to express my gratitude to my project guide Prof. Dr. R.R Sedamkar for his supervision and continuous encouragement in my Master of Engineering programme.

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