K-Means Clustering for Adaptive Wavelet Based Image Denoising

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***Abstract*— Clustering algorithms have been used for systematic retrieval of data by organizing them into several clusters and K-Means is one such algorithm, which partitions data into groups based on distance metric in an unsupervised way. In this paper, we study denoising of images corrupted with variable Gaussian noise spread across the entire images in the dataset. The training dataset was generated by applying K-Means Clustering Algorithm on the statistical parameters calculated from wavelet transformed training images. Noisy test images were denoised by selecting the best statistical parameters belonging to the nearest cluster centroid, which has been subsequently used to denoise the image using Adaptive Soft Threshold. It is also inferred that the cluster centroids obtained models a fuzzy inference engine.**

Keywords*— *K-Means Clustering Algorithm, Image Denoising, Soft Thresholding, Discrete Wavelet Transform.

I. INTRODUCTION

A fundamental step in image processing is the step of removing various kinds of noise from the image. Sources of noise in an image mostly occur during storage, transmission and acquisition of the image. A few examples includes sudden change in image intensities occurring due to faulty switching during imaging, failure of working of the camera sensor pixels, imperfect memory storage sites, sudden positional changes of sensors during camera exposure, present of a noisy channel for transmission of images, de-synchronization during digital recording process, unwanted transitions of bits during image transmission, etc. These sources results in an undesirable signal called as noise, which hampers the original image by interfering with it and thereby degrading the overall quality of the image.

Over the years, several research undertakings have paid attention to model noise from several noise sources. [9] These noise models mostly comprise of information regarding the global distribution of the noise, but combination of noise model distributions doesn't generally produce an effective denoising result in applications present in real life. Moreover, global denoising schemes suffer a drawback as multiple numbers of different images suffers from various combinations of several different types of noise.

Several algorithms for image denoising have been proposed and formulated over recent years, and their application depends primarily on the noise type prevalent on the image. Most of the algorithms can be classified into two major categories: spatial domain and transform domain filtering. Operations that are performed directly on the image comprise of spatial domain filtering, whereas operations performed on transform domain of the image constitute transform domain filtering.

Two types of spatial domain filtering is present, a) Linear and b) Non-Linear filters. The famous linear filters mostly used for the purpose of image denoising are spatial averaging filter and wiener filter. Averaging filters results in removal of sharp transitions in the image by calculating the average of the neighborhood of pixels and replacing the center pixel with the average value. Wiener filter utilizes prior knowledge about the additive noise spectra and the image to perform minimum mean squared error image smoothing corrupted by additive noise and blurring. Non-linear filtering is used mostly to remove salt and pepper noise from an image, whose functionality depends on pixel ordering in a neighborhood focused around a center pixel. Spatial domain filtering suffers mostly from high computational cost and blurring of edges in the image.

Transform domain filtering mostly comprise of filtering of image in different domains such as Fourier, Wavelet, Ridgelet etc. Applying a transform to the image results in generating uncorrelated set of coefficients and is in coherent with the transform compactness property, as a result a sufficient number of transform coefficients can be discarded and store and process only those coefficients that have a bulk of energy within them. Random noise present in the images mostly comprises of low-level energy transform coefficients.

In the recent years, image denoising using unsupervised learning techniques such as K-Means Clustering has gained sufficient focus from various research communities. K-Means clustering is mostly used to group the noisy image into geometrically similar structures. Clusters are described using features that are generated by applying Principal Component Analysis or Linear Discriminant Analysis to generate features of patches across the noisy image. These features are used to estimate the original pixel values using Steering Kernel Regression Framework. [7]

In this paper, we proposed a novel way to denoise images using K-Means Clustering in the wavelet domain using adaptive multilevel soft-thresholding. The rest of the paper is subdivided into the following sections; Section 2 covers the literature survey regarding the latest research work carried in the field of image denoising, soft-threshold and K-Means Clustering, Section 3 explains the basic concepts, Section 4 discusses about the proposed methodology of our work, Section 5 covers Experiments Performed and Results obtained, Section 6 discusses the conclusion of the results obtained.

II. PREVIOUS WORK

A. Khare and U. S. Tiwary previously have denoised images by applying soft thresholding on wavelet coefficients embedded with noise [2]. DB6 was found to give excellent results for the purpose. M. Jonidi et al. have worked on removing image contaminated with Additive Gaussian Noise and minimizing MSE based on clustering techniques [6]. P. Chatterjee et al. have worked on removing noise from noisy image cluster, which was made based on geometric structure. The work was done by altering pixel based on underlying image structure [7].

III. THEORY

A. K-Means Clustering

Clustering divides components of a dataset in a way that the ones having similar properties are allotted to same group or cluster and at the same time components, which differ in properties, are allotted to different group or cluster [3][5]. In this paper clustering is done in testing phase to group thresholding parameters (mean, median and standard deviation) of wavelet coefficients.

The algorithm most commonly in practice is an iterative technique. The steps are as follows:

- STEP 1: Randomly 'k' centers are selected from the given dataset.

  S={x1, x2, x3… xn} € Rm, S is set of points in dataset.

  y11, y12, y13… y1k € Rm, are set of centers

- STEP 2: Assign each point of the dataset to the cluster whose center point is nearest. Now, compute the mean point of the cluster.

  A2i = {x€S: d(x, y1i) <= d(x,y1j) ¥ j!=i}

  Mean (A2i), i=1, 2, 3… c

- STEP 3: Repeat Step No.2, until no new assignments are made.

  If ll y1i – y2i ll <= e

  Then

  STOP with the output A2i

  Else

  A1i = A2i

  A2i = Ø

  GO TO Step 2

B. Daubechies Wavelet

In Numerical Approximation Algorithms (commonly known as Numerical Analysis) Wavelet Transform are nowadays commonly used and gaining more popularity over Fourier Transform. This acceptance has been due to introduction of real space in addition to Fourier space [4][8]. Among several discretely sampled wavelet transforms, Daubechies Wavelet has been incorporated in this work.

Daubechies Wavelet are product of recurrence association which cumulatively generate fine samples of "mother wavelet". The wavelet selected for the purpose of denoising is based on the smoothing level. DB6 has been chosen which gives superior outcome for the chosen application in this work [1][2][4].

C. Thresholding

Higher levels of Wavelet coefficients are affected with noise thus making wavelet coefficients sensitive to noise [reference]. The main motive behind thresholding is to remove the noise present in the coefficients. The two most routinely used thresholding techniques are: a) Soft Thresholding and b) Hard Thresholding [2].

Soft Thresholding has been integrated in our paper as it depends upon the type of image passed in the algorithm. In Soft Thresholding a threshold value is calculated based on equation no. 1.

$$\text{Threshold}(T) = \frac{1}{2^\wedge(j-1)}\left(\frac{\text{Standard Deviation}}{\text{Mean}}\right)(\text{Median}) \quad (1)$$

Where j is level number upon which wavelet coefficients are calculated. Wsoft is equation to determine soft threshold.

$$\text{Wsoft} = \text{sign}(W)\ (|W|-T)_+ \quad (2)$$

where $\text{sign}(a)=\begin{cases}+1 \text{ if } a>0\\ 0 \text{ if } a=0\\ -1 \text{ if } a<0\end{cases}$ (3)

and $(B)_+=\begin{cases}B & \text{if } B>0\\ 0 & \text{otherwise}\end{cases}$ (4)

The values of wavelet coefficients are changed by this threshold value. Values above the threshold are pushed towards zero by an amount equivalent to threshold and values below it are made zero.

IV. METHODOLOGY

The algorithm employed in our work is defined in steps below:

- Training Phase:
  1) Image “Img” are read from the database in a sequential manner.
  2) The read image is converted to grayscale “ImgGray”
  3) Gaussian Noise of variable mean and variance is added to “ImgGray” using non-overlapping blocks of size 3X3 neighborhood to generate the noisy image “ImgNoisy”
  4) 2D- Discrete Wavelet Transform of noisy image is performed for a fixed value of the number of levels for wavelet decomposition.
  5) Image statistics mean, median and standard deviation of the wavelet coefficients at a given level is calculated and stored in a variable “Final” to be used later for the clustering process.
  6) Steps 3 and 5 are repeated for different sizes of neighborhood of Gaussian noise addition such as 5X5, 7X7 and 9X9.
  7) Steps 1-6 are repeated for all the images present in the dataset to generate the training dataset for the clustering process.
  8) The number of cluster centroids is fixed and K-means clustering algorithm is executed for the data stored in the variable “Final”.
  9) The resulting centroids obtained after K-means clustering is stored in a variable “Centroids”.

- Testing Phase:
  10) The noisy test image is read and converted into gray scale to generate the test image “ImgTest”.
  11) 2D- Discrete Wavelet transform of ImgTest is taken for the same number of levels of Wavelet Decomposition used during the training phase.
  12) In a similar manner image statistics such as mean, median and standard deviation of the noisy image is calculated for a particular level and stored in a variable “Test”.
  13) The centroid from the variable “Centroids” which is closest to the variable “Test” is found out using L2 distance norm.
  14) This centroid is used to calculate the value of soft-threshold according to Eqn (1).
  15) The wavelet coefficients are soft thresholded using the value of soft-threshold calculated in step 14.
  16) Finally the output image is reconstructed using the soft-thresholded wavelet coefficients, and its Power Spectrum Noise Ratio (PSNR) is calculated.

V. EXPERIMENTS AND RESULTS

A. *Dataset Used:*

The HOLIDAY dataset was used to train the K-Means Clustering algorithm to generate the initial clusters. This dataset mostly contains personal holiday photos, which were taken to test its robustness against various attacks such as illumination and viewpoint modifications, rotations, blurring etc. High-resolution images are taken comprising of a various types of scenes such as natural, water, man-made and fire effects etc. There are a total of 812 images, each of them grouped into 500 image groups, where each group represents a distinct scene.

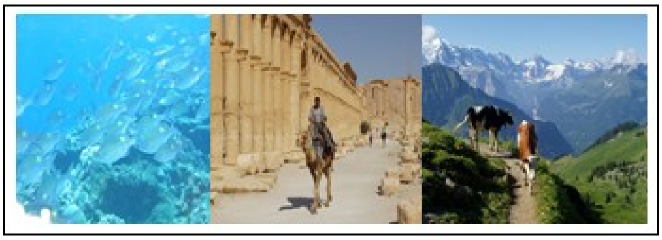
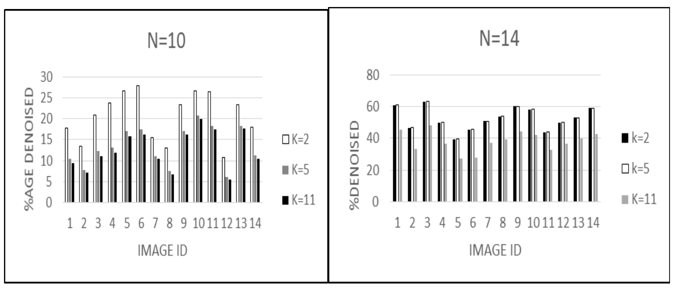


Fig. 1. Three examples of the different types of images present in HOLIDAY dataset.

B. *Results:*

Each image in the dataset was processed according to the training algorithm proposed above to generate mean, median and standard deviation of all the levels of wavelet decomposition, after addition of variable Gaussian noise. These values were then fed as input to K-Means Clustering algorithm with number of centroids fixed to 15. The K-Means Clustering algorithm was executed for 1000 loops to generate the final converged centroids. Thereafter the resultant centroids are used for denoising of sample test images in the wavelet domain using multilevel soft-threshold by varying the number of decomposition levels (N) and number of clusters (K). The various results obtained are shown below:



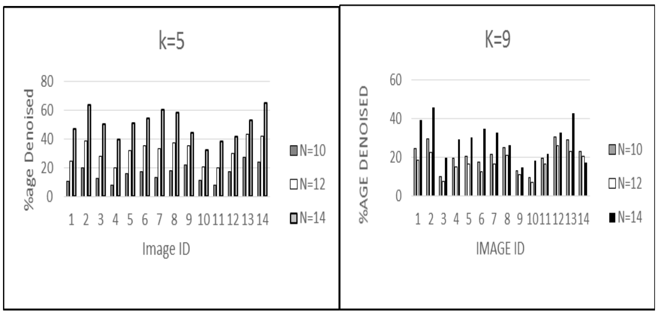
(a) (b)

Fig. 2. The percentage of denoised obtained for 14 Test Images for (a) N=10 and (b) N=14.

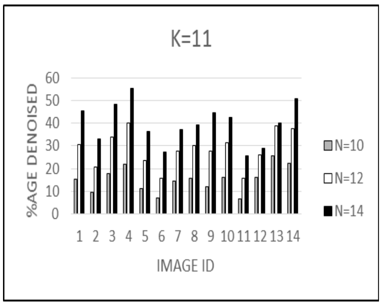
It is observed from the above graphs that percentage of denoised increrases with increasing the level of wavelet decomposition upto a certain extent. The percentage of denoising ranges from 9-28 % when N is fixed at 10, while the percentage significantly rises to 35 to 60 % with N fixed at 14.

This rise in percenatge of denoising is not linear with increase in number of levels of wavelet decomposition. It has been noticed that increasing the level of decompostion beyond 16 leads to reduction in percentage of denoised. A possible explaination for this outcome is that increase in the levels of wavelet decompostion leads to disintegration of the minute coarse details in the image which might not have been affected by the gaussian noise added, and therefore once thresholded, it results in loss of minute details which leads to a poor value of PSNR.

The effect of the number of clusters chosen on percentage denoised across various values of wavelet decomposition is shown below:



(a) (b)



(c)

Fig. 3. The percentage of denoised obtained for 14 Test Images for (a) K=5, (b) K=9 and (c) K=11

Drawing correspondence between Fuzzy Logic System and K-means Clustering, it can be infered that the various cluster centroids obtained after clustering can be thought of as Fuzzy Rules used in Fuzzy Inference Engine. Choosing a smaller value of K such as 5 gives a better percentage of denoising compared to choosing a higher value such as 9 or 11. A possible explanation for this outcome is that a larger value of K leads to modelling of reduntant rules in fuzzy inference engine while a smaller value of K represents non-reduntant rules. Moreover further increase in value of K doesn't significantly reduce the denoising percentage as the fuzzy rules become highly reduntant and thus become ineffective. It is also seen from the graphs above that the best level of wavelet decomposition is 14 where a significant higher value of denoising is obtained.

Three examples of the results obtained are shown below:

Fig. 4. Noisy images of test database (a) image 7, (b) image 13 and (c) image 32

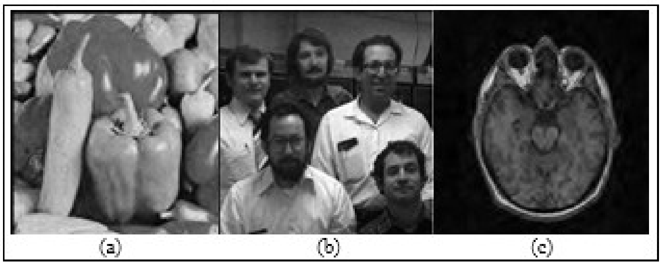


Fig. 5. Denoisy images of test database (a) image 7 (b) image 13 and (c) image 32

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References

[1] Jamal Saedi, Mohammad Hassan Moradi and KarimFaez, "A new wavelet-based fuzzy single and multi-channel image denoising," Elsevier journal, Image and Vision Computing 28(2010) 1611-1623.

[2] Ashish Khare and Uma Shanker Tiwary, "Soft-thresholding for Denoising of Medical Images-A Multiresolution Approach," *International Journal of Wavelets, Multiresolution and Information Processing* Vol 3,N0. 4 (2005) 477-496.

[3] S. K. Bhatia, "Adaptive K-means Clustering," *FLAIRS Conference*, page 695-699. AAAI Press, (2004).

[4] Cedric Vonesch, Thierry Blu and Michael Unser, "Generalized Daubechies Wavelet Families," *IEEE Transactions on Signal Processing*, Vol. 55, No. 9, September 2007.

[5] Shi Na, Liu Xumin and Guan Yong, "Research on k-means Clustering Algorithm An improved k-means Clustering Algorithm," *IEEE Symposium*, 2010.

[6] Mohsen Joneidi et. Al., "A Study on Clustering-Based Image Denoising: From Global Clustering To Local Grouping ." *Journal of Information Systems and Telecommunications (JIST)*. 11/2014; 2(4):196 - 204.

[7] Priyam Chatterjee and Peyman Milanfar, "Clustering-based Denoising wth Locally Learned Dictionaries," *IEEE Transactions on Image Processing*, Vol. 18, No. 7, July 2009.

[8] Hari Om and Mantosh Biswas, "An Improved Image Denoising Method Based on Wavelet Thresholding," *Journal of Signal and Information Processing*, 2012, 3, 109-116.

[9] PriyankaKamboj and Versha Rain, "A Brief Study Of Various Noise Model And Filtering Techniques", Journal of Global Research in Computer Science, Vol. 4, No. 4,April 2013.