Complexity Reduction and Quality Enhancement in Image Coding

Ahmad Shahin, Fadi Chakik, and Safaa Al-Ali

***Abstract*—In this paper we propose an image coding approach based on Alternative Fuzzy c-Means. Our main objective is to provide an immediate access to targeted features of interest in a high quality decoded image. This technique is useful for intelligent devices, as well as for multimedia content-based description standards. The use of AFcM reduces the coding time in comparison to the traditional clustering algorithm FcM. A second stage coding is applied using entropy coding to remove the whole image entropy redundancy. In the decoding phase, we suggest the application of a nonlinear anisotropic diffusion, based on Perona-Malik equation, to enhance the quality of the coded image. Qualitative evaluation confirms the validity of the proposed approach.**

***Index Terms*—Anisotropic non-linear diffusion, entropy coding, fuzzy segmentation, image compression.**

I. Introduction

Data compression becomes an essential challenge in the middle of huge, fast and excessive revolution of technology communication, limitation of hardware and fast sending of data. Thus, storage and transmission of such data require large capacity and bandwidth, which can be very expensive. To reduce the side effects that may cause such problems, data compression techniques were issued so the number of bits required to store or transmit data is decreased with or without loss of information.

Data compression is often guided by the type of data being manipulated and processed: image compression compresses still images; video compression compresses motion picture; etc. Data is presented to a user in an uncompressed format and is stored and transmitted in a compressed format. Therefore, data compression algorithms need to perform two functions, compression and decompression.

A fundamental goal of image compression is to reduce the bit rate for transmission and storage while maintaining an acceptable fidelity or image quality.

Image compression forms the backbone for several applications like storage of medical images in a database, picture archiving, HDTV transmission, video conferencing and facsimile transmission. Compression of images involves taking advantage of the redundancy in pixel data present within an image.

The contemporary image compression methods are dominated by concepts that involve the discrete cosine transform (DCT), such as the JPEG standard, or the discrete wavelet transform (DWT), in JPEG2000. Those methods provide both good quality and high compression rate despite the loss of unrealized information [2].

Lastly, PDE steps in and it's now the essential element in image compression and restoration [5]. The idea behind applying PDE is to code some points of the image (Landmarks) that are selected based on many criteria such as edges or corners while in decoding we are going to have a sparse image in which incomplete information will be filled by using the PDE diffusion (anisotropic diffusion) [9].

In this study, we suggest the merge of the fuzzy clustering AFcM and PDEs in order to achieve good image quality after compression with a possibility to define image features by the mean of clustering or segmentation.

The structure of this article is as follows: In section 2, we describe the system architecture for image compression/decompression. We will also summarize the main techniques on which the system depends. Experiments and tests are presented in section 3.

II. Procedure for Paper Submission

In Fig. 1, we show the block diagram of the proposed compression and decompression system which is a modification of the algorithms proposed in [14]. The major modification is the use of the fuzzy clustering AFcM instead of FcM.

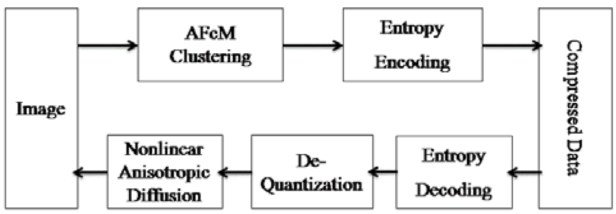

Fig. 1. The suggested image compression system using AFcM segmentation and non-linear anisotropic diffusion.

The steps in the proposed algorithm are as follows:

- Unsupervised Fuzzy clustering is applied on the input image. The FcM proposed by Bezdeck [1] is often a good tool to achieve image segmentation. In our work, we apply the AFcM [11] which is based on the FcM but which converges faster and hence will reduce the coding time. At the end of this step, well-defined members are assigned to the cluster C with the highest membership. These members will be coded with the code of C.
- A second phase of coding is applied. Here entropy coding will help reducing the large amount of redundancy. Multiple studies was performed and improved to find effective techniques in order to encode information without dropping their principal entities [12].

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Among different algorithms recently applied, we may take into consideration Huffman [13] or Arithmetic [10].

On the other side, the decompression phase reconstructs image from compressed data by applying:

- Entropy decoding.
- De-quantization assigns the well defined members with the corresponding cluster center.
- Applying non-linear anisotropic diffusion [6, 7]: The pixel value issued from class centers will be used in the final step by applying non-linear anisotropic diffusion as a restoration technique to improve the image quality.

The quality of the reconstructed image is controlled by many parameters such as the choice of the number of clusters, the number of iterations in the diffusion phase…

In this section, we'll describe the two main parts of our system: The clustering technique AFcM and the non-linear diffusion method.

A. The Fuzzy Clustering

Clustering is the process of organizing objects in groups having similar properties. Clustering methods can be used to create groups of pixels that are similar in regard to a measure, often their color or gray level; therefore simplifying the image by reducing the number of discrete possible pixel values. Image clustering can be used to get a simple segmentation of the image.

The Alternative Fuzzy c-Means algorithm (often abbreviated to AFcM) [11] is an iterative algorithm inspired from FcM proposed by Bezdeck [1]. These algorithms find clusters in data and use the concept of fuzzy membership: instead of assigning a pixel to a single cluster, each pixel will have different membership values on each cluster.

The AFcM attempts to find clusters in the data by minimizing an objective function shown in the equation below:

$$J = \sum_{i=1}^{C}\sum_{j=1}^{N}\mu_{ij}^{m} d^2(x_j, c_i) \tag{1}$$

where:

- ***J*** is the objective function, a kind of quality criterion to minimize
- ***N*** is the number of pixels in the image
- ***C*** is ***the*** number of clusters used in the algorithm, and which must be decided before execution
- ***μ*** is ***the*** membership matrix -- of *N*x*C* entries which contains the membership values of each pixel to each cluster
- ***m*** is a fuzziness factor (a value larger than 1)
- x_j is ***the*** *jth* pixel in the image
- c_i is ***the*** *ith* cluster
- d(x_j, c_i) is the distance between x_j and c_i. In the FcM, the Euclidian distance is used while in the AFcM it's defined as:

$$d^2(x, y) = 1 - e^{-\beta\|x-y\|^2} \tag{2}$$

where $\beta > 1$ and could be estimated from the image variance $\bar{x}$ as:

$$\beta = \left(\sum_{j=1}^{n}\left\|x_j - \bar{x}\right\|^2 / n\right)^{-1} \tag{3}$$

This metric is a robustness estimator because it is insensitive to small variations and robust against noise [11]. The steps of the algorithm are:

- Initialize μ with random values between zero and one; but with the sum of all fuzzy membership elements for a particular pixel being equal to 1 -- in other words, the sum of the memberships of a pixel for all clusters must be one.
- Estimate β using (3)
- Calculate an initial value for J using (1).
- Calculate the centroids of the clusters c_i using

$$c_i = \frac{\sum_{j=1}^{n}\mu_{ij}^{m}\,[1-d^2(x_j,c_i)]\,x_j}{\sum_{j=1}^{n}\mu_{ij}^{m}[1-d^2(x_j,c_i)]} \tag{4}$$

- Calculate the fuzzy membership μ_{ij} using

$$\mu_{ij} = \left(\sum_{k=1}^{C}\frac{\left[d^2(x_j,c_i)\right]^{1/(m-1)}}{\left[d^2(x_j,c_k)\right]^{1/(m-1)}}\right)^{-1} \tag{5}$$

- Recalculate *J*.
- Go to step 4 until a stopping condition was reached.

Some possible stopping conditions are:

- A number of iterations were executed, and we can consider that the algorithm achieved a "good enough" clustering of the data.
- The difference between the values of *J* in consecutive iterations is small (smaller than a user-specified parameter ε), therefore the algorithm has converged.

Traditionally the algorithm *defuzzify* its results by choosing a "winning" cluster, i.e. the one which is closer to the pixel in the feature space, is the one for which the membership value is highest and using that cluster center as the new values for the pixel. These membership values can be obtained for any kind of images (grayscale, RGB, etc…). The algorithm is adaptive and can be used with image of multiple channels.

B. Non-Linear Diffusion

The PDEs used in image restoration (smoothing, denoising, enhancing of image...) [5] are almost the same PDEs used in image compression by the diffusion (linear isotropic or nonlinear anisotropic).

Typical PDE techniques for image smoothing regard the original image as initial state of a parabolic (diffusion-like) process, and extract filtered versions from its temporal evolution.

Many evolution equations for restoring images can be derived as gradient descent methods for minimizing a suitable energy functional, and the restored image is given by the steady-state of this process.

This theory was proposed by Malik and Perona [6,7]. Their main idea is to introduce a part of the edge detection step in filtering itself, allowing distinguishing noise from edge. The principle is to spread strongly in areas with low gradients (homogenous areas), and low in areas with strong gradients (edges). These filters are difficult to analyze mathematically, as they may act locally like a backward diffusion process.

Perona and Malik proposed a nonlinear diffusion method for avoiding the blurring and localization problems of linear diffusion filtering. They applied an inhomogeneous process that reduces the diffusivity at those locations which have a larger likelihood to be edges. This likelihood is measured by $\|\nabla u\|^2$. The Perona-Malik filter is based on the equation:

$$\partial_t u = div(g(|\nabla u|^2)\nabla u) \qquad (6)$$

And uses the diffusivity:

$$g(s^2) = \frac{1}{1+s^2/\lambda^2} \quad (\lambda > 0) \qquad (7)$$

The experiments of Perona and Malik were visually very impressive: edges remained stable over a very long time. For more details, see [6].

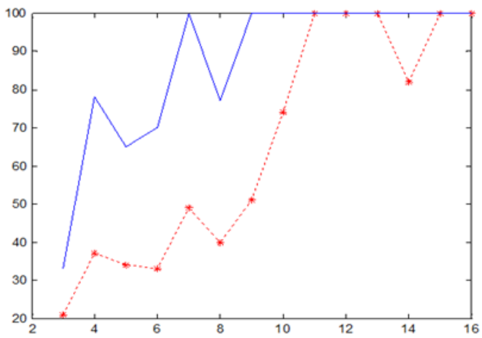
III. Experimental Results

We have conducted our experimental tests on three well known benchmarks of grayscale images: Lena, Barbara and Baboon. Each image is of size 512*512.

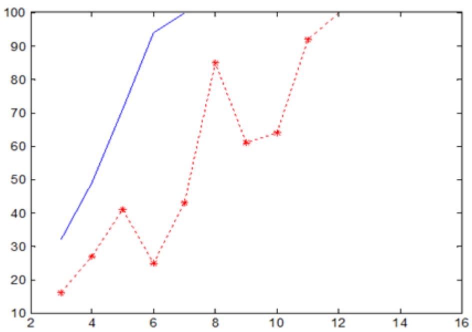
There are two main arguments on which the efficiency of our system depends:

- The complexity of the clustering technique.
- The qualitative improvement of the anisotropic diffusion phase.

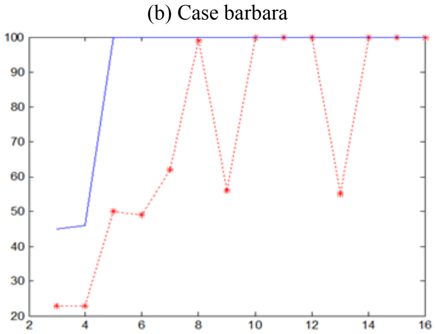
A. Reducing the Complexity of the Clustering Technique



(a) Case lena



(b) Case barbara



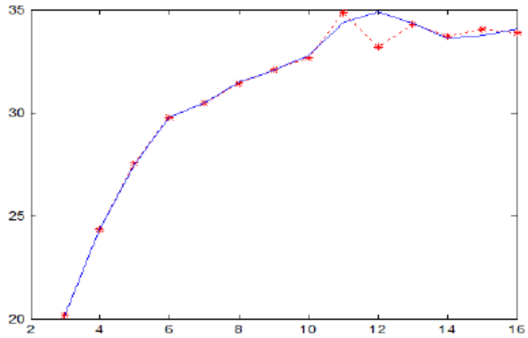
(a) Case lena

Fig. 2. AFcM (dashed curve) is faster than FcM (regular curve) with Lena image: The horizontal axis represents the number of clusters. The vertical axis indicates the number of iterations for the clustering algorithm

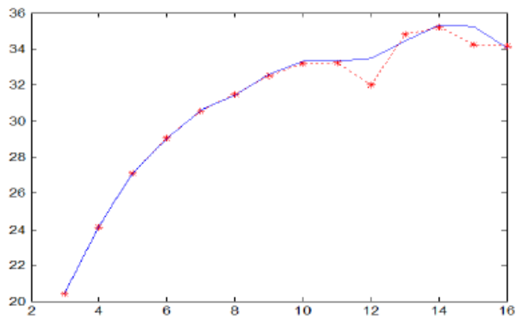
Our main objective in this study is to reduce the complexity of the clustering algorithm. So, we applied the AFcM in order to reduce the number of iterations and hence reduce the compression time. Fig. 2 shows clearly that AFcM converges faster than FcM when applied on the Lena, Barbara, and Baboon images.

We have previously conducted a quantitative study using the FcM in [14]. The application of FcM as a clustering tool in the compression phase and the anisotropic diffusion in the decoding phase were very promising and the results obtained were very satisfactory and closed to those obtained by JPEG [14].

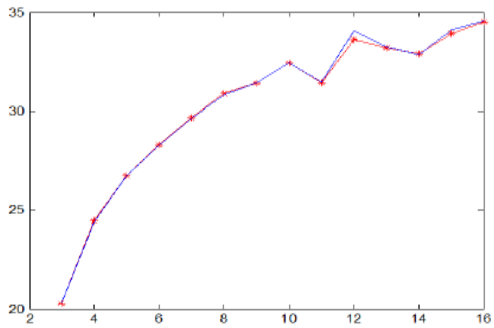
It's primordial to measure the quality of the coded image issued from the clustering algorithm. Our experimental results proved that, when using AFcM, the quality of the image, based on the PSNR, is very similar to the quality when applying FcM (see Fig. 3).



(a) Case lena



(b) Case barbara



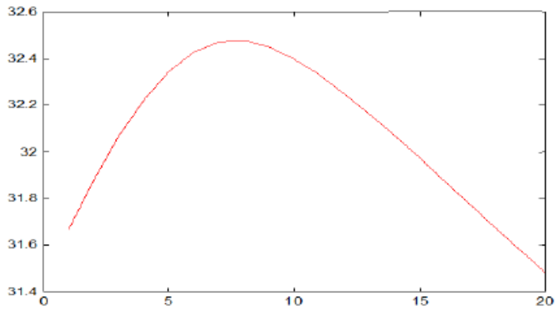
(c) Case Baboon

Fig. 3. PSNR as a function of number of clusters: The quality achieved by AFcM (dash starred curve) is very close to the quality obtained by FcM (regular curve)

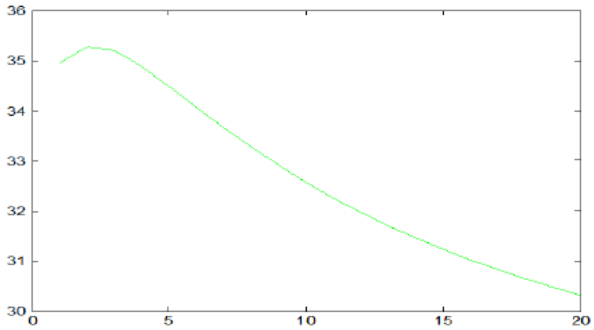
B. Influence of Anisotropic Diffusion

Quality improvement in a decoded image could be obtained by applying the Perona-Malik operator. The experimental results show that this PDE filter increases the PSNR after very little iteration.

In Fig. 4, we see the influence of PDEs on the Lena image quality for C = 8 (a) and C = 16 (b) respectively with AFcM. It's clear that the anisotropic diffusion operator increases the PSNR.

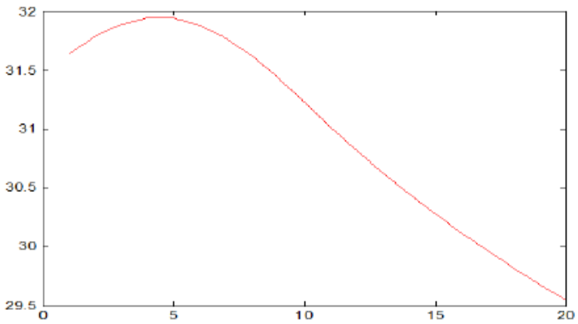


(a) C = 8, the PSNR reaches its maximum after 7 iterations

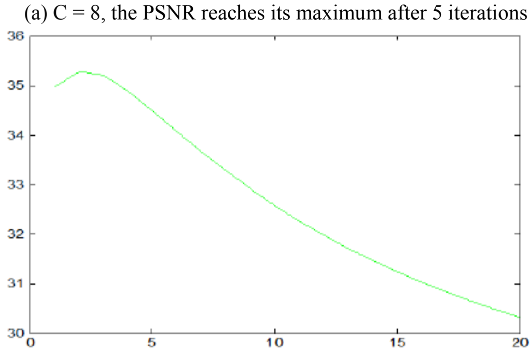


(b) C = 16, the PSNR reaches its maximum after 4 iterations

Fig. 4. PSNR increases after few iterations on Lena Image: Horizontal axis indicates the number of iterations when applying the PDE filter, the vertical axis is for PSNR

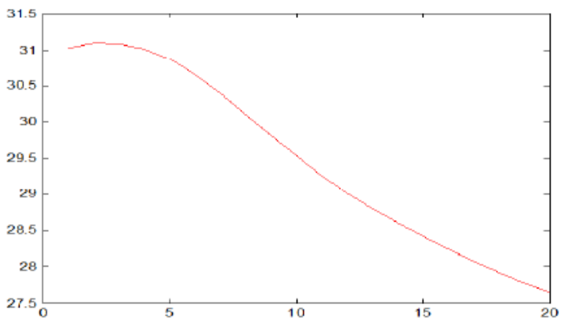


(a) C = 8, the PSNR reaches its maximum after 5 iterations

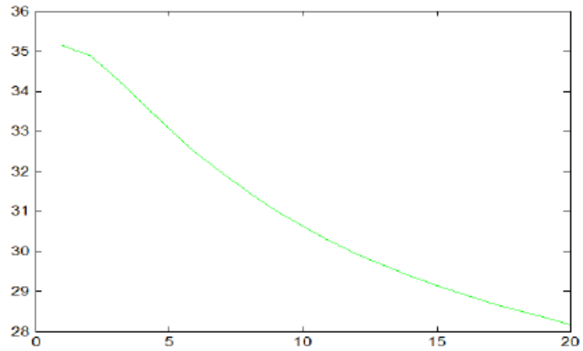


(b) C = 16, the PSNR reaches its maximum after 3 iterations

Fig. 5. PSNR increases after little iteration on barbara image.



(a) C = 8, the PSNR reaches its maximum after 3 iterations



(b) C = 16, the PSNR reaches the maximum at the first iteration

Fig. 6. PSNR increases after little iteration on Baboon Image.

In [3], [4], the authors presented a log-based technique that achieves a compression ratio (CR) of 14.85 on Lena image with a PSNR = 29.89. Our technique achieves a PSNR = 26 without PDE and a PSNR = 27.85 after anisotropic diffusion with a CR = 15.27.

Similar tests were applied on Barbara and Baboon images. In Fig. 5 and Fig. 6, we show the results of segmentation on Barbara and Baboon for C = 8, and C = 16 respectively.

IV. Conclusion

We have presented a qualitative based approach for image compression. Our proposed system is based on fuzzy image segmentation, the AFcM, to build the so called codewords. This method permitted us to segment an image more rapidly than using the well-known method FcM. The experimental results had shown that PDEs often increase the PSNR in little iteration and hence offer better quality. The application of a PDE method and the number of iterations to apply should be indicated in the header of the coded image. These results were promising and are close to the result obtained by the standard JPEG.

We believe that introducing ambiguity factor in the clustering phase could be beneficial for the decoding phase and especially with the use of non linear anisotropic diffusion. Also, we'd like to work on segmentation algorithms that integrate this ambiguity notation such as the Fuzzy c+2 Means introduced by [8]. We should also conduct tests on better anisotropic filters such as CED or EED [5] to enhance the diffusion quality. We'd like to test the efficiency of our approach for the compression of big pictures in order to work on these pictures with normal PCs, notebooks, iPad etc.

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