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COLOR IMAGE COMPRESSION USING VECTOR QUANTIZATION WITH FUZZY LOGIC

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ABSTRACT
Image compression is a critical method for minimizing digital image size for efficient storage and transmission, particularly in bandwidth-constrained applications. A new approach for color image compression by incorporating vector quantization (VQ) and fuzzy logic is introduced in this paper with the aim of further improving performance. Vector quantization is another commonly used lossy compression technique in which an image is divided into small blocks and mapped to a prechosen set of representative vectors called codewords, thereby compressing the image considerably.
In order to solve the problem of maintaining image quality while compressing it, we apply fuzzy logic to increase the accuracy of the codeword selection mechanism. Using the fuzzy logic rules, we define the selection rules adaptively based on the characteristics of the image in order to achieve maximum balance between compression ratio and image quality. Application of fuzzy logic enables smoother movement from one region of images with similar content to another and eliminates quantization errors characteristic for VQ, especially in regions of high variance of pixel intensity.

The new hybrid method was applied to several color images and was proven to surpass the traditional VQ method in terms of compression ratio, PSNR, and SSIM measures. The hybrid method offers an efficient plan for high-compression-quality-image with little computational cost.

Keywords: Image Compression, Compression Ratio, Vector Quantization, Fuzzy Logic.

1. INTRODUCTION

The volume of color pictures taken, disseminated, and stored is increasing by leaps and bounds during the age of high-speed development in digital photography and multimedia technologies. For efficient storage and bandwidth utilization without loss of image quality, efficient image compression is required. Because of the higher data capacity and inter-channel correlation, color image compression, which involves compressing RGB or other multi-channel color representation schemes, is more complex than for gray-scale images [1].

Vector quantization (VQ) is a very commonly used lossy image compression technique. Through the division of images into non-overlapping blocks and the conversion of each of these blocks to a fixed number of representative vectors—also called a codebook—it compresses images. Though capable of providing a large degree of compression, VQ does not generally maintain image integrity, particularly in regions of sudden change or detail [2].

Fuzzy logic application to VQ has been of interest as a solution to such difficulties. Fuzzy logic, based on human decision-making, provides a theoretical framework for handling uncertainty and vagueness. Fuzzy rules enable image compression algorithms to be adapted locally based on local features of an image, enhancing entry selection within a codebook and retaining subtle features and smooth color changes [3].

This study aims to develop a hybrid approach that effectively compresses color images by applying fuzzy logic and VQ. This approach enhances image quality, compression ratios, and minimizes artifacts by making use of the versatility of fuzzy rules to adjust the VQ process. This hybrid approach proves useful particularly when the image quality must remain high even after compression, like in medical imaging, satellite remote sensing, and multimedia data.

One of the areas of research in the compression of images is the hybridization of fuzzy logic and VQ that overcomes the visual quality vs. compression efficiency trade-off. Exposing the potential of the hybrid approach in color image compression, contrasting it to more traditional methods, and highlighting its benefits in real-world applications, this study aims to advance this discipline [4].

2. RELATED WORK

In photograph compression, one of a kind strategies may be employed to compress photos. Hashim Adnan et al. [5] delivered a technique that mixes the SPIHT and DWT algorithms, ensuring less facts loss at the same time as attaining high compression ratios. Medical photos may be compressed with efficiency without affecting their diagnostic nice the use of the DWT and SPIHT algorithms. By appreciably minimizing the storage requirements of medical pictures, the proposed approach allows for faster records transmission and better storage.

Mohammed Fadhil Radad et al. [6] proposed a method that integrates VQ and DWT. The intention of the proposed method for clinical photo compression is to hold a excessive compression ratio even as maintaining the diagnostic content material of the picture intact. Discrete wavelet rework (DWT) changed into utilized to compress the data in addition, and thresholding changed into determined to be the quality approach for growing coefficients. The BPNN method turned into then implemented to vector-quantize the output. The recommended approach obtains an splendid tradeoff among compression ratio and photograph pleasant, accordingly enhancing compression overall performance.

Garima Garg et al. [7] proposed a technique which integrates two latest techniques, SVD and DCT. The input photo is to start with decomposed into three man or woman channels: the crimson channel, the green channel, and the blue channel. These 3 channels are then surpassed via the manner of SVD, which yields a single picture as output after reconstruction of each character channel and application of the compression process. Second, the DCT technique is carried out to the output generated. The image is again separated into three exclusive colorations, and then the value of power coefficient is calculated with the aid of utilizing those channels. The threshold is determined by using determining the energy coefficient price, that's the coefficient with the most cost.

Marwa B. Al-Obeidi et al. [8] counseled a method for coloration photo compression with the goal of decreasing their size. The approach splits the photo into two bands: a non-supply band for the pink and blue channels, and a source band for the green channel. The source band is encoded the use of a lossless 2D linear polynomial approach in one of these way that the compressed picture does not lose its first-class. The experimental consequences show that the suggested method outperforms traditional techniques of compression or even surpasses the widely used JPEG approach. Secondly, the method presents good compression with maintaining best picture quality. The proposed technique offers higher performance over JPEG with an photo length reduction of about thirteen.Eight KB and compression ratio (CR) of approximately 14. The proposed method basic offers a possible technique to color image compression that offers an road to make colour photographs smaller with out compromising on their best.

Shamsul Fakhar et al. [9] introduced an image compression method based on singular price decomposition (SVD) by extracting RGB channel colorations. This approach efficaciously keeps photo high-quality with a decrease inside the storage area required for images. The size of the garage photo is minimized via the SVD via casting off useless pixel values relying on RGB colors. The experimental take a look at of two kinds of image extensions (i.E., jpg and png) indicates that the SVD can compress photographs with minimal loss of picture great.

Apoorva Hegde et al. [10] improved color image compression using a block optimization approach like rank filtering. Color reduction follows, which is accomplished by using the byte compression approach to achieve the best compression. The proposed compression method achieves the required level of compression. The computed PSNR is then compared with the earlier method.

Shyama Akram [11] suggested a new model that uses a support vector machine to identify the features of greyscale images that are retrieved from two steps in order to produce a colour image from an initial greyscale image. The vector that combines with the six statistical data (mean, variance, skewness, kurtosis, energy, and standard deviation) taken from the greyscale image in the second stage is first configured using the Haar Discrete Wavelet Transform..

Shih-Lun Chen et al. [12] presented a novel real-time process image compression and high compression ratio very-large-scale integration (VLSI) architecture for Internet of Things (IoT) image sensors. YEF transformation, colour sampling, Golomb-Rice coding, threshold optimisation, subsampling, block truncation coding (BTC), prediction, and quantisation are all included in the design. The optimal answer for the parameters is obtained by training different parameters using machine learning. Two ideal reconstruction values and bitmaps are generated for each 4 by 4 block. In order to remove inter-pixel duplication and carry out numerical translation, BTC divides an image into 4 by 4 blocks.

3- METHODOLOGY

One crucial stage in the compression of color images is preprocessing. By eliminating redundant information, improving pertinent aspects, and guaranteeing compliance with the compression method, it gets the picture data ready for effective compression. The RGB color space is transformed into a visually consistent color system, such as YCbCr, to make processing color pictures easier. The bright information is represented by Y (luminance). The color information is represented by Cb and Cr (chrominance). Since human vision is more sensitive to luminance than to chrominance, this reduces redundancy across color channels [13].

To remove noise without affecting edges and important information, a Gaussian filter is applied. This phase ensures that noise will not adversely affect the compression process.

Subsequently, the LH, HL, HH high-frequency sub-bands are ready to serve as inputs for the hybrid VQ-Fuzzy Logic system and the LL coefficients are encoded using zigzag ordering followed by Huffman coding technique. Supplying parameters like block size or weights in color channels and organizing pixel information into vectors are some examples of this.

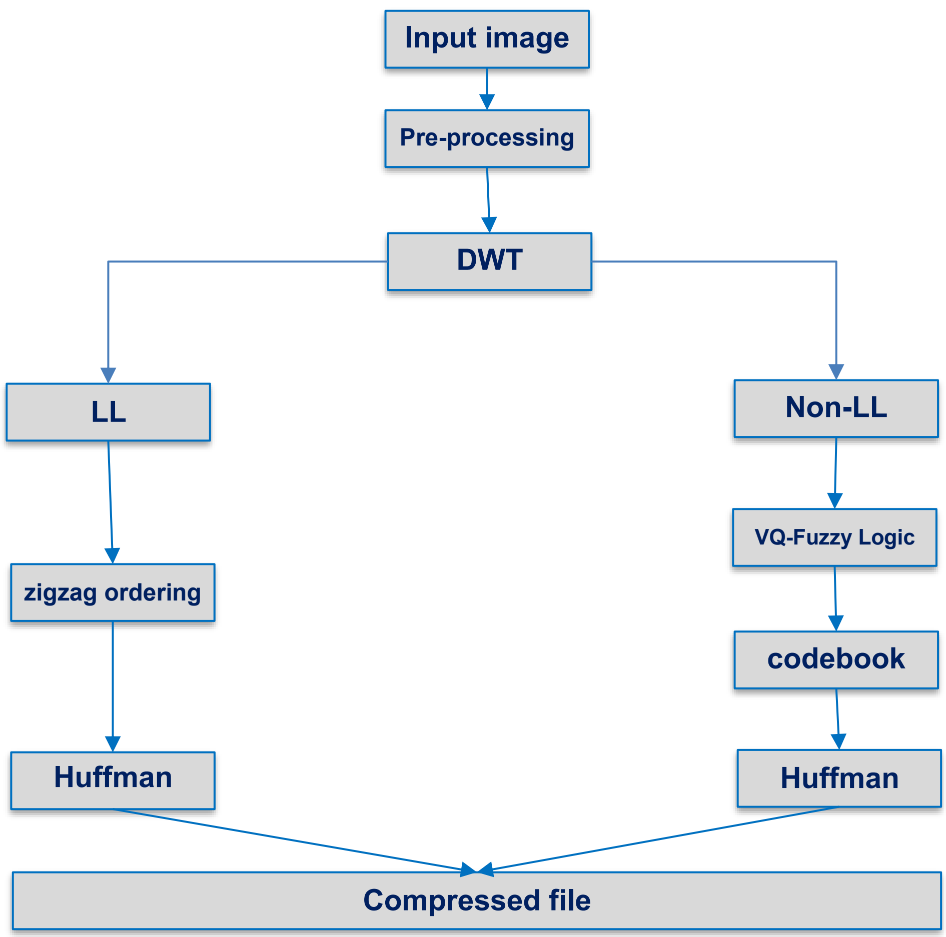


Figure 1. Block Diagram of the Proposed Model.

3.1 PREPROCESSING OF IMAGES

Color image pre-processing is essential for reducing noise, processing data, and ensuring compatibility with subsequent methods prior to compression or analysis.

This process entails applying the conversion algorithm to convert the RGB input image to the YCbCr color space. The YCbCr color space makes compression simpler by isolating brightness from color information and applying the Gaussian filter to each channel (Y, Cb, Cr). Unwanted noise will not hinder image analysis or compression due to the Gaussian filter [14].

the YCbCr components are calculated as:

$$Y = 0.299R + 0.587G + 0.114B \qquad \text{Eq. (1)}$$

$$Cb = 128-0.1168736R - 0.331264G + 0.5B \qquad \text{Eq. (2)}$$

$$Cr = 128 + 0.5R - 0.418688G - 0.081312B \qquad \text{Eq. (3)}$$

Gaussian function is:

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \qquad \text{Eq. (4)}$$

3.2 DISCRETE WAVELET TRANSFORM

After preprocessing, the final image is sent through several distinct wavelet decomposition stages. The frequency modules are revealed through the various wavelet decomposition stages. Additionally, it improves the picture data for distributed use. Additionally, it covers methods for technique reconstruction after compression. The reason for this is that the latter levels minimize noise while offering more helpful information[15].

A 1-D approach is used to manage a 2D picture due to its ability to process images quickly and efficiently. After that, the image's columns and rows are disassembled. To accomplish the switching, filters are applied to the columns and rows of the 2D picture. It is employed because the Cohen Daubechies 9/7 filter can produce a lot of zeroes or vanishing moments.

The image is divided into four sub-bands: the LL sub-band, which contains the low-frequency information in both dimensions; the LH sub-band, which contains the high-frequency information in the horizontal course; the HL sub-band, which contains the high-frequency information in the vertical course; and the HH sub-band, which contains the high-frequency information in the diagonal course [16].

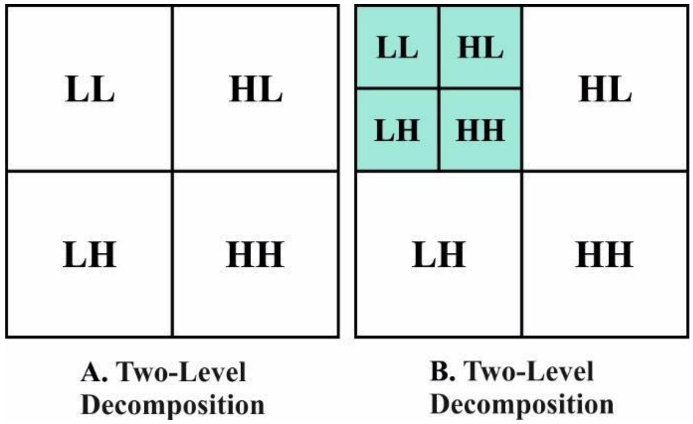


Figure 2. Sub-bands segmenting of image [16].

3.3 VECTOR QUANTIZATION WITH FUZZY LOGIC

The most effective and potent technique for image compression is vector quantization, or VQ. The VQ treatment is applied to the whole collection of resulting coefficients produced by the thresholding stage. That is, it is treated in the same way as other sub-bands, save the LL sub-band, in the first and second situations. The LL sub-band's components undergo a zigzag-like sequential scanning operation. This phenomenon is frequently referred to as either the conventional zigzag transformation or the zigzag confusion. Vector quantization aims to minimize the error between compressed and uncompressed pictures, and the main challenge in this field is efficient codebook (CB) generation [17].

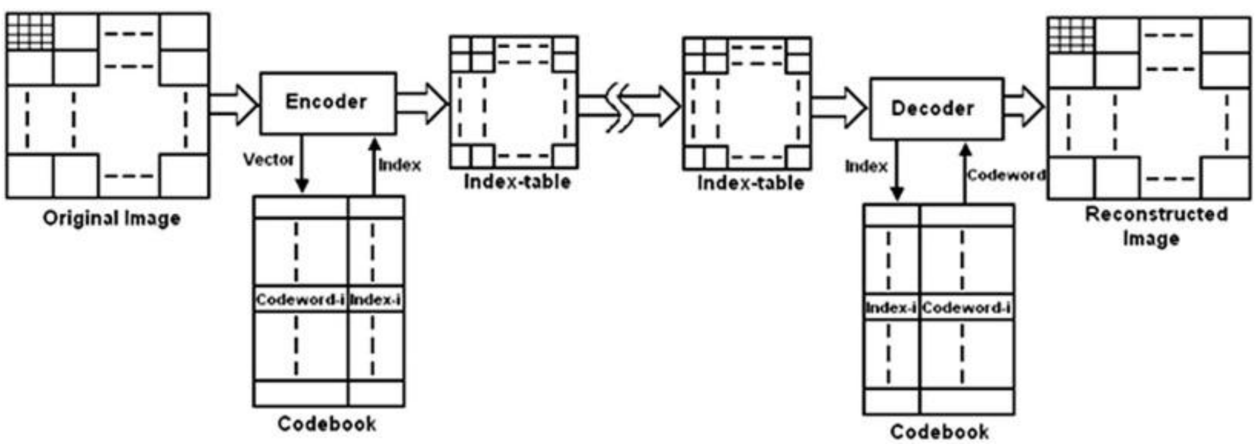


Figure 3. Vector quantization [18].

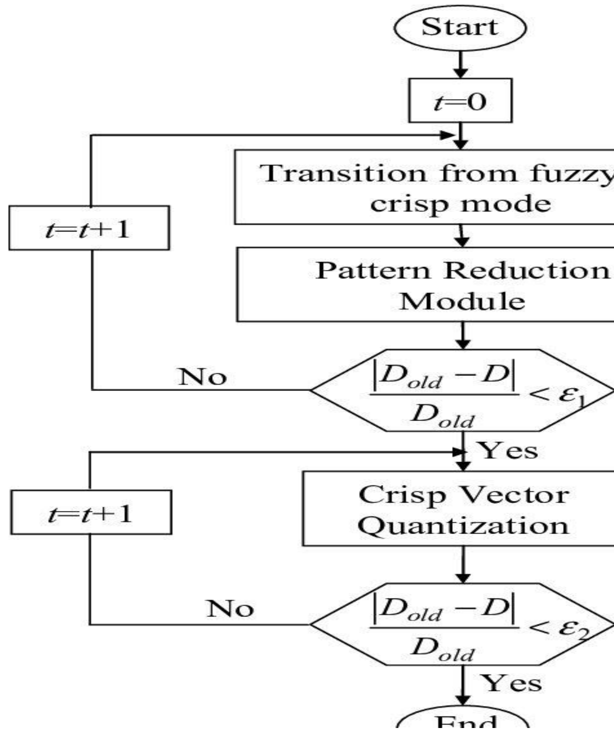


Figure 4. Vector quantization with fuzzy logic[19].

3.4 CODING OF IMAGE

The Huffman Coding method is a form of entropy encoding that may be used for both picture and data compression without sacrificing the integrity of any important data. By using their code in conjunction with the encoded sequence, which is composite, the decoder successfully restores the original image. This ensures correct decoding. To successfully restore the compressed picture, the next step will be to reverse the compression process and return the image to its original condition.

The first stage involves decoding the material that was encoded using Huffman Coding to extract the indexes. Subsequently, the index compilation is moved to the VQ, where it is decoded with the codebook to reconstruct the functional data. Upon fixing the wavelet coefficients, the decoder will now search the code word in the codebook using the indexes.

The LL sub-bands are then appended to the data thereafter. After this process, zeroes are appended to the data again to account for the two sub-bands lost during compression. An inverse DWT is employed as the final process in the picture restoration process. The restored picture should be of the same size as the original [20].

4- PERFORMANCE MEASUREMENT

There are several ways to assess an image compression algorithm's performance, including: -

- Compression Ratio: This is the proportion between the original image's size and the compressed image. An image that has been compressed more effectively has a greater compression ratio. This formula can be used to determine the compression ratio.:

$$Compression\ Ratio = \frac{uncompressed\ file\ size\ (byte)}{compressed\ file\ size\ (byte)} \qquad \text{Eq. (5)}$$

-Mean Square Error (MSE): This is an additional metric for comparing the original and reconstructed images. A better reconstruction is indicated by a lower MSE value. This formula can be used to determine MSE:

$$MSE = \frac{1}{M*N}\sum_{i=1}^{M}\sum_{j=1}^{N}(f(x,y) - g(x,y))^2 \qquad \text{Eq. (6)}$$

where f and g are pictures of M*N size. This measure is useful since it gives an estimate of the energy lost when the original image is compressed using Lossy.

- Peak Signal-to-Noise Ratio (PSNR): In comparison to the original image, this gauges how well the reconstructed image is rendered. Better reconstruction quality is indicated by a higher PSNR value. The following formula is what we employ:

$$PSNR = 10\log_{10}\left[\frac{255^2}{MSE}\right](db) \qquad \text{Eq. (7)}$$

5- RESULTS AND DISCUSSIONS

In this part, experimental findings are used to evaluate the effectiveness of the recommended vector quantization with fuzzy logic. Using a computer with an Intel(R) Core (TM) i7-2620M CPU 2.70 GHz (4 CPUs), ~2.7 GHz with Windows 10 Professional, calculations pertaining to this topic have been performed using MATLAB 2022. Table 1 provides examples of compression ratios and PSNR values for the image.

Table 1. Evaluation of VQ with Fuzzy Logic approach performance on number of images.

parameters	CR	PSNR	MSE
 Lena	**17.27**	**38.62**	**3.57**

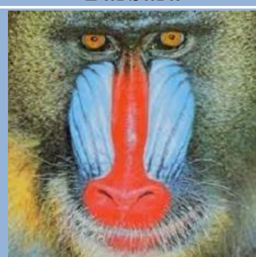
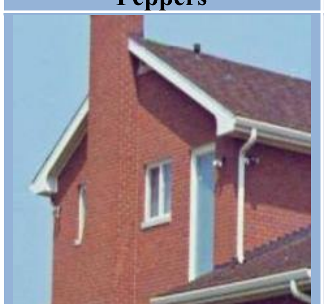
 **Barbara**	**16.65**	**39.07**	**3.18**
 **Baboon**	**14.25**	**35.74**	**7.45**
 **Peppers**	**13.34**	**39.85**	**3.03**
 **House**	**18.22**	**37.92**	**4.09**

Table 2. Comparison with the traditional model.

Image	Proposed model		JPEG	
	CR	**PSNR**	**CR**	**PSNR**
Lena	17.27	38.62	8.06	36.53
Barbara	16.65	39.07	9.23	33.07
Baboon	14.25	35.74	8.95	33.85
Peppers	13.34	39.85	8.45	34.71
House	18.22	37.92	9.58	34.54

6- CONCLUSION

Fuzzy logic and vector quantization (VQ) combined with color picture compression offer a notable boost in compressed image quality and efficiency. This hybrid method combines fuzzy logic's capacity to manage imprecision and uncertainty in data with VQ's strengths in grouping.
VQ drastically decreases storage requirements by encoding comparable pixel blocks into representative codebook vectors, hence reducing redundancy. By adding fuzzy logic, the clustering procedure is improved, and pixel data is represented more accurately. By giving data degrees of membership, fuzzy logic improves the compression algorithm's flexibility and produces transitions that are smoother and fewer artifacts in reconstructed pictures. This method preserves a high level of visual integrity, which is particularly important for color photos.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Each author made the following contribution to this study: Conceptualisation, technique, writing the first draft, writing the review and editing, and visualisation fall under the purview of the first and second. Formal analysis and data curation are under the purview of the third author.

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