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Lossless Compression of VC Shares in RGB Color Space

M. Mary Shanthi Rani
Department of Computer Science and Applications
Gandhigram Rural Institute – Deemed University, Dindigul,
Madurai, India

G.Germine Mary
Department of Computer Science
Fatima College, India

Abstract: Visual Cryptography is a special encryption technique to hide information in images in such a way that it can be decrypted by the human vision if the correct key image is used. In Visual Cryptography the reconstructed image after decryption process encounters a major problem of Pixel expansion. This is overcome in this proposed method by minimizing the memory size using lossless image compression techniques. Image compression is minimizing the size in bytes of a graphics file without degrading the quality of the image to an unacceptable level. The reduction in file size allows more images to be stored in a given amount of disk or memory space. It also reduces the time required for images to be sent over the Internet or downloaded from Web pages. Hybrid techniques are used in this proposed method as it can exploit multiple kinds of redundant information.

Keywords: Visual Cryptography; HVS; Image Compression; Vector Quantization; Run Length Encoding; Huffman Coding

I. INTRODUCTION

In today's high technology environment, organizations are becoming increasingly reliant on their information systems. The public is concerned more and more about the proper use of information, particularly personal data. The threats to information systems from criminals and terrorists are on the rise. Headline news scares about stolen or misplaced data are becoming an everyday occurrence. So it is important to protect information and its secrecy. Addressing privacy and security concerns requires a combination of technical, social, and legal approaches.

Cryptography is the practice and study of techniques for secure communication in the presence of adversaries. Cryptography refers to encryption, which is the process of converting ordinary information called plaintext into unintelligible text called cipher text. Decryption is the reverse, in other words, moving from the unintelligible ciphertext back to plaintext. [1].

Visual Cryptography (VC) is a cryptographic technique which allows visual information (pictures, text, etc.) to be encrypted in such a way that decryption is done by Human Visual System. One of the best-known techniques has been developed by Moni Naor and Adi Shamir in 1994 [2].
Modern cryptography including VC has four objectives:

- Confidentiality - the information cannot be understood by anyone except for whom it was intended
- Integrity - the information cannot be altered in storage or transit between sender and intended receiver
- Non-repudiation - the sender of the information cannot deny at a later stage his intentions in the transmission of the information
- Authentication - the sender and receiver can confirm each other's identity and the origin/destination of the information

VC schemes conceal the secret image into two or more images which are called shares. The secret image can be recovered simply by stacking the shares together. Each of the shares looks like a group of random pixels and of course, looks meaningless by itself [3]. Naturally, any single share, before being stacked up with the others, reveals nothing about the secret image and hence are very safe. This way, the security level of the secret image when transmitted via the Internet can be efficiently increased.

In this secret image sharing scheme, the size of the shares is 4 times the size of the original image due to pixel expansion. This disadvantage of VC can be overcome by image compression before it is shared over the network.

Image Compression is the process of reducing the number of bits required to represent an image[4]. Compression has traditionally been done with little regard for image processing operations that may precede or follow the compression steps. In this proposed scheme compression follows VC as it results in pixel expansion. Data compression is the mapping of a data set into a bit stream to decrease the number of bits required to represent the data set. With data compression, one can store more information in a given storage space and transmit information faster over communication channels. Thus, if data can effectively be compressed wherever possible, significant improvements of data throughput can be achieved. In some instances, file sizes can be reduced by up to 60-70 %. Many files can be combined into one compressed document making sending easier, provided combined file size is not huge.

Strategies for Compression are reducing redundancies and exploiting the characteristics of human vision [5]. The two types of data compressions are lossless and lossy. Lossless compression has an advantage that the original information can be recovered exactly from the compressed data. The proposed system performs lossless compression using hybrid techniques of Vector Quantization (VQ), Run Length Encoding (RLE), Huffman Encoding (HE) and Predictive Coding. The principal approach in data compression is the reduction of the amount of image data (bits) while preserving information (image details).

The main objectives of this proposed method are to formulate a secret sharing system which has the following characteristics.

- Exploit the advantage of VC to create meaningless shares to hide secret
- Minimizing the drawback of VC, that is image expansion, by employing multistage hybrid Image Compression techniques

The entire paper is organized in the following sequence. Section 2 various types of data redundancies and compression techniques used in this paper are precisely outlined , section 3 Methods of compression are explained, In section 4 results are presented and discussed. Lastly, section 5 includes conclusions.

II. REVIEW OF COMPRESSION TECHNIQUES

The necessity for efficient image compression techniques is ever increasing since the original images need large amounts of disk space, which is a huge disadvantage during transmission & storage. Though a lot of compression techniques already exist, a better technique which is faster, memory efficient and that suits the requirements of the user is under investigation. In this paper, a Lossless method of image compression and decompression is proposed using a hybrid coding algorithm with higher performance for the special type of Visual Cryptography images. The proposed technique is simple in implementation and utilizes less memory. A software algorithm has been developed and implemented to compress and decompress the given image using three different hybrid techniques in MATLAB platform.

During the past three decades, various compression methods have been developed to address major challenges faced by digital imaging. These compression methods can be classified broadly into lossy or lossless compression. Lossy compression can achieve a high compression ratio, 50:1 or higher since it allows some acceptable degradation. Yet it cannot completely recover the original data. On the other hand, lossless compression can completely recover the original data [4].

Data compression is defined as the process of encoding data using a representation that reduces the overall size of data. This reduction is possible when the original dataset contains some type of redundancy. The basis of the compression process is the removal of redundant data. Digital image compression is a field that studies methods for reducing the total number of bits required to represent an image. This can be achieved by eliminating various types of redundancy that exist in the pixel values. In general, three basic redundancies exist in digital images: Psycho-visual redundancy, Interpixel redundancy, and Coding redundancy. Data compression is achieved when one or more of these redundancies are reduced or eliminated. In the proposed system a multi-step algorithm combining all the types of redundancy factors is used to reduce and eliminate the redundancy.

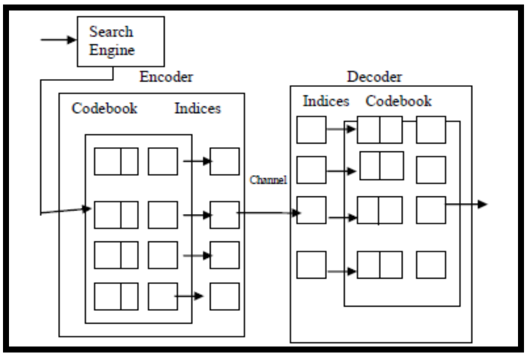


Figure 1. Vector Quantization Scheme.

To reduce psycho-visual redundancy we use Quantizer. The elimination of psychovisually redundant data may result in a loss of quantitative information. It is commonly referred to as quantization. Quantization is a many-to-one mapping that replaces a set of values with only one representative value. Scalar and vector quantization are two basic types of quantization. Scalar quantization (SQ) performs many-to-one mapping on each value. Vector Quantization (VQ) replaces each block of input pixels with the index of a vector in the codebook, which is close to the input vector by using some closeness measurements (Fig. 1.). The decoder simply receives each index and looks up the equivalent vector in the codebook [6-8].

Another important form of data redundancy is interpixel redundancy, which is directly related to the inter-pixel correlations within an image. Because the value of any given pixel can be reasonably predicted from the value of its neighbors, the information carried by individual pixels is relatively small. Once the correlation between the pixels is reduced, we can take advantage of the statistical characteristics and the variable length coding theory to reduce the storage quantity. This is the most important part of the image compression algorithm; there are a lot of relevant processing methods available. The best-known methods are Predictive Coding and Run Length Encoding (RLE). Both are lossless coding methods, which mean that the decoded image and the original image have the same value for every corresponding element [6,9].

Run length coding replaces data by a (length, value) pair, where "value" is the repeated value and "length" is the number of repetitions (Fig. 2). This technique is especially successful in compressing bi-level images since the occurrence of a long run of a value is rare in ordinary gray-scale or color images. It does not work well at all on continuous-tone images such as photographs, although JPEG uses it quite effectively on the coefficients that remain after transforming and quantizing image blocks.

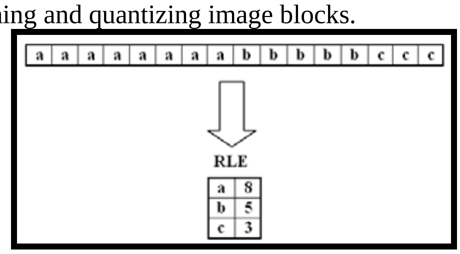


Figure 2. RLE Scheme.

An entropy encoding is a coding scheme that involves assigning codes to symbols so as to match code lengths with the probabilities of the symbols. Typically, entropy encoders are used to compress data by replacing symbols represented by equal-length codes with symbols represented by codes proportional to the negative logarithm of the probability. Therefore, the most common symbols use the shortest codes.

Coding Redundancy reduction is done in Huffman coding. The Huffman's algorithm is generating minimum redundancy codes compared to other algorithms. The Huffman coding has effectively used in text, image, video compression, and conferencing system such as JPEG, MPEG-2, MPEG-4, and H.263 etc. The Huffman coding technique collects unique symbols from the source image and calculates its probability value for each symbol and sorts the symbols based on its probability value. Further, from the lowest probability value symbol to the highest probability value symbol, two symbols combined at a time to form a binary tree (Fig. 3). Moreover, allocates zero to the left node and one to the right node starting from the root of the tree. To obtain Huffman code for a particular symbol, all zero and one collected from the root to that particular node in the same order [10].

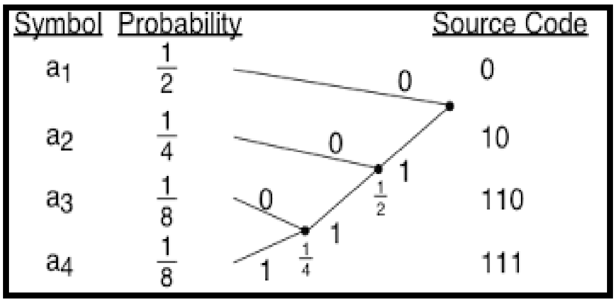


Figure 3. Huffman Coding Scheme.

III. Proposed System

The algorithm for the proposed VC compression is based on the techniques discussed in section 2. VC shares are created for the secret color image X by means of the following procedure. Every pixel in the image $X_{(m.n)}$ is split into 3 color channels (RGB). Two shares are created for every color channel depending on the intensity of pixel values of each color channel [11-13]. Each pixel in every color channel is extended into a two 2×2 block to which a color is assigned according to the model presented in Fig. 4, and each block is composed of two black pixels and two color pixels. Fig. 4, depicts the 2X2 blocks created for Red channel. The blocks are combined to form Share1 and Share2 for the red channel. In a similar way Share3 and Share4 for green channel and Share5 and Share6 for the blue channel are created [8]. At the end of the process, six shares are created. The six shares created will look like random dots and will not reveal any information since they have an equal number of black and color pixels. Finally, the shares of RGB, to be exact, the Shares 1, 3 and 5 are merged to form VC share1 and similarly Share2, Share4 and Share6 are merged to form VC share2 as in Fig. 5(b) and 5(c) respectively.

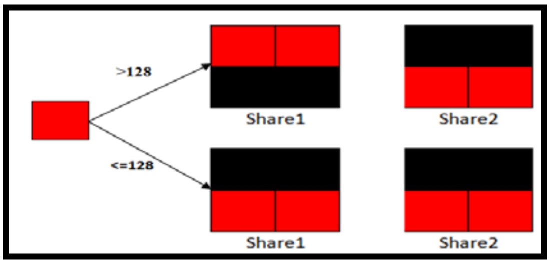


Figure 4. Share creations for red channel.

In Fig. 5, the SI (a) is decomposed into two visual cryptography transparencies (b) and (c). When stacking the two transparencies, the reconstructed image (d) is obtained. The VC shares (fig. 5a and 5b) are sent through the network. The size of each share is 1024X1024 and the total bytes transmitted will be 6291456 bytes (2X1024X1024X3). The objective of this article is to explore different means of reducing the bit rate without compromising the quality of the image.

Figure 5. (a) Color SI (b) Encrypted VCshare1 (c) Encrypted VC share2 (d) Decrypted SI.

A. *Method 1 (VQRLE)*

In this method, VQ technique is applied to the generated VC shares. The basic idea of this technique is to develop a dictionary of fixed-size vectors, called code vectors (Code Book). A vector is usually a block of pixel values. A given image is then partitioned into non-overlapping blocks (vectors) called image vectors of size 4 for each of RGB channel separately. The vector with 4 bits for each RGB channel is compared with the predefined vector used for creating shares to check if it represents maximum intensity(255) or minimum intensity(0) in the original image and the code (0 or 255) is assigned accordingly. RGB values in the image vector are compared with the code vectors in the dictionary and its index in the dictionary is determined which is used to encode the original image vector. Thus, each image is represented by a sequence of indices and is stored in a Vector Index Table (VIT) as shown in Fig. 6. The size of VIT will be equal to the no of blocks that is one-fourth of the no. of columns / rows of the image.

The decoder simply receives each index and looks up the corresponding vector in the codebook. Here vector Quantization of the blocks, replaced in lieu of a pixel in VC is substituted with a code and it results in lossless compression as the redundancy block is manageable. The size of VIT is further reduced by applying RLE algorithm. This is a very simple compression method used for sequential repetitive data. This technique replaces sequences of identical symbols (index value in our case), called runs in a separate vector. The Index in VIT has just 8 values from 1 t0 8 to represent the index of code vector. This is passed as an input to RLE algorithm. RLE creates two vectors, one to represent the arrangement of the element and the other to represent the runs of the element. VQRLE encoding process is shown in Fig. 6.

VQRLE - Algorithmic Description

Input : VC Share1 and VC Share2 created as output of the algorithm 3.3.1.1

Output : Compressed VC Share1 and VC Share2

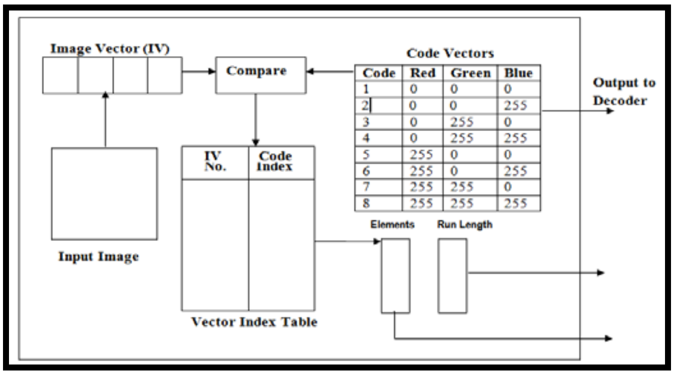
BEGIN

1. Read Secret Image that is to be transmitted securely across network
2. Extract RGB components from each pixel in SI
3. Check the pixel value of the red (green/blue) component which ranges from 0 – 255
4. According to the value of pixels, each pixel is replaced with a 2X2 block and create share1 and share2 as shown in Fig. 4
5. Repeat step 3 and step 4 for green and blue colors to create share3, share4, and share5, share6 respectively
6. Shares 1, 3 and 5 are merged to form VC share1 and similarly Share2, Share4 and Share6 are merged to form VC share2
7. Consider the RGB components of the share1 and share2 separately and convert each component into blocks of size 2X2 and then to a vector of size 4.
8. For each pixel block in share1 and share2 compare the RGB vector with the predefined vector used for creating shares to check if it represents maximum intensity (255) or minimum intensity (0) in the original image and assigns code accordingly. The Code book has 8 vectors and given in Table 1.
9. Create Vector Index Table (VIT) which contains block number and codebook index
10. Index in VIT has a sequence of 8 values from 1 to 8 to represent the index of the codebook. This is passed as an input to RLE algorithm
11. RLE creates two vectors, one to represent the arrangement of element and the other to represent the length of the element. These two vectors and the code book is the final output sent to the receiver

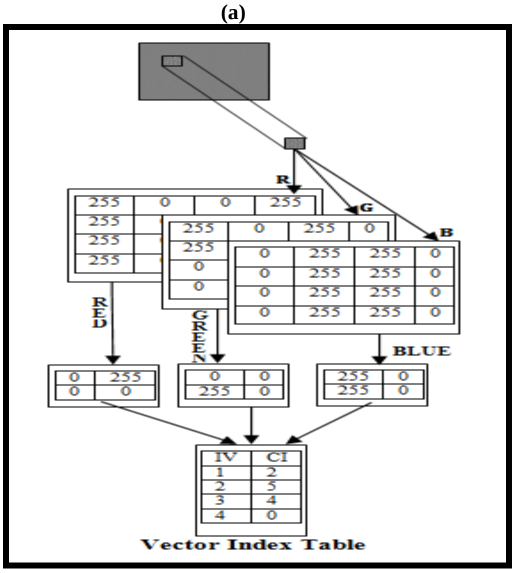
END

B. Method 2 (VQPCHE)

The second method uses the principle of predictive coding followed by Huffman encoding to reduce the size of VIT. In predictive coding the difference in pixel values between neighbouring pixels is calculated. To the predictive code generated Huffman encoding algorithm is applied. Huffman encoding is a general technique for coding symbols based on their statistical occurrence frequencies (probabilities). The values generated are treated as symbols. The symbols that occur more frequently are assigned a smaller number of bits, while the symbols that occur less frequently are assigned a relatively larger number of bits. Huffman code is a prefix code. This means that the (binary) code of any symbol is not the prefix of the code for any other symbol. Probability is calculated for the difference and Huffman code is applied.



(a)



(b)

Figure 6. (a) VQRLE architecture (b) VIT creation

VQPCHE - Algorithmic Description

Input : Secret Image

Output : Compressed VC Share1 and VC Share2

BEGIN

1. Steps 1-9 are repeated as in algorithm VQRLE
10. Index in VIT has a sequence of 8 values from 1 to 8 to represent the index of the codebook. This is passed as an input to a predictive coding algorithm where the difference in code values between adjacent vectors is calculated and stored as a vector.
11. For the predictive vectors, Huffman coding algorithm is applied and the values are replaced with codes and sent across the network.

END

C. Method 3 (VQHE)

In this method, Huffman encoding is used followed by Vector Quantization to compress the given image. To the VIT table values, which ranges from 1 to 8 probability is calculated and Huffman encoding is applied as discussed above.

VQHE Algorithmic Description

Input : Secret Image

Output : Compressed VC Share1 and VC Share2

BEGIN

1. Steps 1-9 are repeated as in algorithm VQRLE
10. Index in VIT has a sequence of 8 values from 1 to

8 to represent the index of the codebook. The probability of the sequence is calculated and Huffman code is generated based on the probability.

11. Generated Huffman code is sent across the Network.

END

The compressed images are decoded by reversing all the previously explained steps to get the original image.

IV. Results and Discussions

Using the above-proposed method experiments are conducted on several RGB test images of size 512 x 512 pixels and 2 x 2 pixel block size using Pentium Dual-Core processor at 2.53 GHz with 3 GB RAM. The performance of the proposed method is evaluated using standard compression metrics like peak signal-to-noise ratio (PSNR), compression and decompression time, and bit rate in bits per pixel (BPP), compression ratio and structured quality index (Q) to measure the quality of the reconstructed image.

The proposed algorithm focuses on sending the secret image in the compressed form. Hence the SI is first converted to VC shares and different compression techniques are employed to the VC shares. Three lossless image compression methods are proposed and their experimental results are given in Table I, II and III respectively.

A. Performance Analysis of proposed methods

1) PSNR: In statistics, the mean square error (MSE) measures the average of the squares of the "errors", that is, the difference between the original image and recovered image. The peak signal-to-noise ratio (PSNR) in decibels is computed between two images. This ratio is often used as a quality measurement between the original and the reconstructed image [14]. The higher the PSNR value better is the quality of the reconstructed image. PSNR is most commonly used to measure the quality of reconstruction of lossy compression. The signal, in this case, is the original data, and the noise is the error introduced by compression.

PSNR is most easily defined using MSE. Given a noise-free m×n monochrome image I and its noisy approximation K, MSE is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

(1)

The PSNR (in dB) is defined as:

$$PSNR = 20\log_{10}\left(\frac{Max|I|}{\sqrt{MSE}}\right)$$

(2)

PSNR value for RGB color channels is infinity for all images in all the methods confirming all the methods used is a lossless compression.

2) Bit Rate: The compression efficiency is also measured by the bit rate, which is the average number of bits required to store a pixel and is computed as follows [4].

Bit Rate = $\frac{C}{N}$ (bits per pixel)

(3)

where C is the number of bits in the compressed file and N is the number of pixels in the original image. The bit rate for all images in VQHE method is very low compared to other two methods. The bit rate for Lenna shares in VQHE is only 0.169, contrary to VQRLE value of 0.52. For VQPCHE it is 0.215. Similarly, the bits per pixel values for Baboon and Peppers image are 0.187 and 0.166 respectively for VQHE and 0.502 and 0.512 for VQRLE. All the three schemes show higher bit rate for Lenna, Peppers and Baboon shares compared to Barbara and Castle shares. This shows the distribution of colors in Lenna, Peppers, and Baboon image is inconsistent. The bpp for Barbara and Castle shares are low signifying the uniform color distribution in some regions of the image.

3) Compression Ratio: Data compression ratio is the ratio of the original file size to the compressed file size. This shows how much compression is achieved for a given image and it is evident that higher compression ratio results in drastic reduction in the size of the compressed file.

Compression Ratio = uncompressed size/compressed size

(4)

VQHE method achieves higher compression ratio in the renge between 42-48 compared to other methods. It can also be observed from table 3 that a high compression ratio of 48.57 is achieved for Barbara and Castle shares. Compression ratio is less than 20 for all the images in the VQRLE method. Compression ratio ranges between 35.2 and 41.2 in VQPCHE method.

4) Compression Speed: It is the amount of time required to compress and decompress an image. This value depends on a number of factors such as the complexity of the algorithm, efficiency of Software/Hardware, implementation of the algorithm etc. Compression speed helps to rate the efficiency of the algorithm.

Tables 1 to III illustrate the compression and decompression speed for the test images in all the proposed methods. Compression speed is less than 4 seconds in method1, less than 10 seconds in method2 and less than 7 seconds in method3. The decompression time is least in VQRLE method compared to other methods. If decompression time is the pertinent criteria then it is preferred to choose the first method with least decompression time and little high bit rate. The decompression time is around 90 seconds for VQPCHE and VQHE. Table 1 to 3 explains that there is a tradeoff between compression speed and bit rate.

*5) Structured Similarity Index (Q)***:** A quality assessment measure for images called the Universal Image Quality Index, Q was proposed by Wang *et al.*[15] which is defined as

$$Q = \frac{4\sigma_{xy}\mu_x\mu_y}{(\sigma_x^2+\sigma_y^2)(\mu_x^2+\mu_y^2)}$$

(5)

where μ_x and μ_y, σ_x and σ_y represent the mean and standard deviation of the pixels in the original image (x) and the reconstructed image (y) respectively. σ_{xy} represents the correlation between the original and the reconstructed images. The dynamic range of Q is [-1, 1] [16]. The best value 1 is achieved for all the sample images in all the proposed lossless compression schemes that reveal the proposed method retains the exact original image after decompression.

TABLE I. Experimental Results of VQRLE

Image	*Compression Time (sec)*	*Decom pression Time (sec)*	*Bits per pixel*	*Compression Ratio*
Baboonvc1	3.43	2.08	0.5026	15.916
Baboonvc2	3.41	2.07	0.502	15.93
Lenavc1	3.27	2.01	0.5202	15.37
Lenavc2	3.31	2.05	0.5203	15.37
Peppersvc1	3.29	2.014	0.512	15.63
Peppersvc2	3.34	2.051	0.512	15.624
Barbaravc1	3.26	2.029	0.406	19.68
Barbaravc2	3.74	2.113	0.406	19.70
Castlevc1	3.256	2.041	0.447	17.91
Castlevc2	3.136	2.053	0.447	17.9

Table III. Experimental Results of Vqpche

Image	*Compression Time (sec)*	*Decom pression Time (sec)*	*Bits per pixel*	*Compression Ratio*
Baboonvc1	8.6106	101.40	0.2273	35.206
Baboonvc2	7.6670	84.089	0.2271	35.236
Lenavc1	8.594	115.81	0.2152	37.188
Lenavc2	10.618	87.7504	0.2150	37.2083
Peppersvc1	6.5702	82.6985	0.2061	38.8289
Peppersvc2	8.2631	95.5889	0.2061	38.8266
Barbaravc1	6.6840	93.6973	0.1979	40.4320
Barbaravc2	6.7975	96.6710	0.1978	40.4414
Castlevc1	8.2308	94.2672	0.1942	41.1971
Castlevc2	7.0568	92.3726	0.1940	41.2405

Table IIIII. Experimental Results Of VQHE

Image	*Compression Time (sec)*	*Decompression Time (sec)*	*Bits per pixel*	*Compression Ratio*
Baboonvc1	5.7613	81.5155	0.1874	42.6925
Baboonvc2	6.6243	82.8625	0.1872	42.7332
Lenavc1	6.1735	92.467	0.1693	47.2494
Lenavc2	7.2314	90.6275	0.1695	47.1967
Peppersvc1	6.6091	86.3930	0.1655	48.3399
Peppersvc2	8.2269	94.2518	0.1660	48.21
Barbaravc1	9.9938	95.7755	0.1646	48.5997
Barbaravc2	6.6731	110.0518	0.1647	48.5743
Castlevc1	6.1334	89.3450	0.1647	48.5753
Castlevc2	6.0751	81.0485	0.1650	48.4828

6) Comparison with standard compression formats: The evaluation of the number of bytes necessary to store the test images using standard file formats like bmp, png, jpeg, gif, and the proposed methods are shown in table 4.

The Joint Photographic Experts Group (JPEG) has selected the Discrete Cosine Transform (DCT) for its baseline coding technique. The fidelity loss in JPEG coding occurs entirely in quantization and much of the compression is gained by run length coding of coefficients which quantize to zero. The VC shares are unique as it allows only two intensity values (0 and 255) for each of RGB Channels. Therefore the application of DCT is not suitable for such images and hence the number of bytes needed to store the images in jpeg format is high. For the same reason, the proposed methods yield a good result and are shown in fig. 7.

Table IVV. Comparative Analysis of File of Compressed Images in Standard File Formats and Proposed Methods

Image	BMP (bytes)	PNG (bytes)	JPEG (bytes)	J2K (bytes)	GIF (bytes)	TIF (bytes)	ZIP (bytes)	VQRLE (bytes)	VQ PCHC (bytes)	VQHC (bytes)
Baboonvc1	3,145,782	196,701	691,571	220,033	265,948	885,976	191,961	197,630	89,378	73,689
Baboonvc2	3,145,782	197,193	691,310	220,050	265,789	885,262	192,518	197,394	89,299	73,610
Lenavc1	3,145,782	194,357	696,231	219,951	251,965	844,572	189,819	204,551	84,620	66,571
Lenavc2	3,145,782	194,553	696,425	219,952	253,565	847,564	189,932	204,590	84,581	66,650
Peppersvc1	3,145,782	181,068	718,619	219,836	248,884	845,956	176,715	201,327	81,042	65,077
Peppersvc2	3,145,782	180,447	718,352	220,182	249,184	846,250	176,116	201,327	81,042	65,273
Barbaravc1	3,145,782	166,299	591,521	220,182	215,349	764,104	162,147	159,646	77,817	64,723
Barbaravc2	3,145,782	166,454	590,664	220,156	216,391	767,036	162,293	159,646	77,778	64,763
Castlevc1	3,145,782	161,921	566,695	220,170	209,448	735,598	157,709	175,768	76,363	64,763
Castlevc2	3,145,782	162,346	566,806	220,058	209,801	736,702	158,254	175,768	76,284	64,881

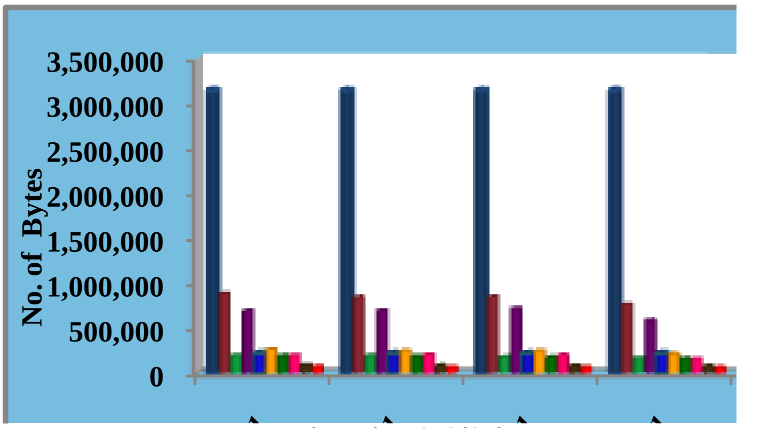


Fig.ure 7. Comparison of size of standard file formats

It is obvious from the experimental results shown in Tables I - IV, our proposed methods outperform similar compression formats achieving higher compression ratios. More specifically, VQPCHE and VQHE are able to achieve a reduction in file size to half of that of other compression formats.

V. Conclusion

A novel Image compression technique for secret image sharing scheme is proposed in this paper. The disadvantage of VC is overcome in this by using repeated hybrid compression techniques. The results show that the technique used is lossless compression. Hence the shares received by the receiver are exactly the same as the sender. The proposed

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