A Novel Approach to Compression and Encryption of Large Color Images

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Abstract- *Satellite images usually have greater size and high redundancy which makes communication systems face bandwidth and storage issues. In addition to that, privacy of the images is also to be preserved. Hence, satellite image communication requires high image compression and unbreakable encryption. This paper combines the compression and encryption techniques into two encoding phases. In the first encoding phase, the proposed JPEG-lossless compression algorithm is optimized by using subsampling technique instead of conventional down sampling approach to reduce color resolution to lower bandwidth of the input space image. Then, in the second encoding phase, compressed image is encrypted using one dimensional chaotic image encryption algorithm by generating logistic maps and cubic maps. The experiments were carried out on various satellite images of different file formats using MATLAB image processing toolbox functions like compress and dct. From the results, it is observed that MSE, PSNR, compression ratio of the compression scheme is around 2%, 56% and 76% respectively, and encryption method showed UACI, NPCR and Information entropy of around 33.5%, 99.3% and 7.85 respectively, that shows an enhanced performance comparatively. Hence the proposed method assists space researchers in working with large satellite images for secured image transmission.*

Keywords— Image compression, image encryption, quantization, chaotic encryption, bandwidth, subsampling, mean square error, peak signal to noise ratio, entropy.

1. INTRODUCTION

Satellite images are large with high resolution and contrast. Hence, these images utilize more bandwidth that makes their investigation complex. Firstly, network transmission becomes slow due to the high onboard storage. Secondly, these images are prone to intruder attacks when transmitted through network channels. Insecure transmission of the images can lead to security breach [1]. Also, these images contain confidential data about the research. Hence, their network transmission also should be secure. These two limitations of the satellite images make them difficult to be used in the satellite communication. Efficient space requirements and image security must be achieved to transmit the large satellite images through network. Large satellite images are compressed using JPEG-lossless compression algorithm and encrypted using chaotic encryption algorithm [2].

In this paper, we propose an algorithm for optimized JPEG-lossless compression of large satellite images. One-dimensional chaotic image encryption technique is used to encrypt the compressed images. The important contribution of this research uses a combination of lossless compression and chaotic image encryption. The proposed method shows optimization in the compression algorithm metrics such as: compression ratio, Mean Square Error (MSE), Peak-Signal-to-Noise Ratio (PSNR). Encryption metrics such as: Unified Average Changing Intensity (UACI), Number of Pixels Change Rate (NPCR) and Information entropy is also considered.

This research paper has been organized as follows. Section II reviews numerous published algorithms for color image compression and chaos-based encryption of images. Section III describes the proposed method for Optimized JPEG-lossless compression and effective chaotic encryption. Section IV describes the results and discussion. Section V presents the conclusion and the future work.

2. LITERATURE REVIEW

Survey is carried out on image compression and encryption separately to review the strength and weakness of various algorithms.

2.1 Survey on Image Compression

Compression tends to decrease the large images in to smaller size images thereby, preserving the information without any considerable loss. Loss of information during compression phase leads to deterioration of image quality. Resolution of the image is very important after compression. Image compression can either be lossy or lossless. Lossy compression algorithms tend to loss of data. Lossy compression algorithms include Chroma-Subsampling [3], Block-truncation coding [4], Vector Quantization [5], Fractal coding [6], Transform coding [7] and sub-band coding [8]. Lossy compression techniques can cause partial discarding of data to present the content. Lossy image compression techniques lead to loss of information with the higher ratio of compression. Also, compressing satellite color images result in high time complexity. Lossy compression algorithms cannot be used in compressing satellite images since it works by removing data.

Lossless compression algorithms provide good compression ratio with higher image quality of reconstructed image. Lossless compression techniques have a very little loss of information while decompression process. These techniques have less time complexity compared to lossy compression techniques Lossless compression algorithms include: Huffman encoding [9], RLE coding [10], LZW coding [11], and Area coding [12].

Discrete Cosine Transform (DCT) based color image compression techniques are found to be efficient in compressing large color images. Maglogiannis et al. [13] suggested region-based compression of RGB color images using inference based fast merging. The lossy compression scheme which is region based for color images was proposed. The compression efficiency was not achieved.

Deepak et al. [14] proposed a color image lossless compression algorithm using inter-color correlation analysis. Natural images were featured by their high correlation among their RGB color pixel components. The compression process was efficient, but the resolution of the decompressed image was low.

Ruchika et al. [15] presented a color image compression process using adaptive based color quantization. The aim of noncognitive compression method was to eliminate the redundancy of images visually and maintain the visceral quality of decoding result. The quality of the reconstructed image was good, but it failed to achieve efficiency resulting low execution speed.

Malarvizhi et al. [16] suggested a color image revival based on DCT-domain vector. A categorization for color image retrieval based on DCT-domain. The method had good execution speed, but the reconstructed image had high space complexity. Vijendra et al. [17] suggested a color image compression based on the concept of principal component analysis technique, which is of two-dimension for face illustration and recognition. The method was successful in compressing only small size images, was not efficient in compressing large images.

2.2 Survey on Image Encryption

Image encryption is also necessary when it comes to security concern of images over the media channel. Image encryption algorithms ensure privacy and protection of images by converting them in to coded images. Image encryption algorithms include techniques like Triple DES [18], Blowfish [19], two-fish [20], RSA [21]. Chaos based cryptography techniques provides faster encryption speed and small key space compared to standard image encryption methods.

Nien et al. [22] proposed method for image encryption consisting with four chaos-based systems and pixel shuffle can completely discard the boundaries of the source image, confuses the disseminate features of RGB components, and completely decreases the chances of comprehensive attacks and the method failed to prove efficient for larger input images and Pixel shuffle mechanism. Fred Jordan et al. [23] proposed a new procedure based on a fractal coding and decoding technique. A fractal coder accomplishes the spatial redundancy within the image by organizing a relationship between its different components. The process was not efficient against blurring attack.

Eshghi et al. [24] formulated an approached that generated a random bit sequence, chaos-based logistic arrays and tent maps are generated. Pixels of the source plain image are changed using the inbuilt chaotic methods. The image blocks are divided in to the 8-bit map planes in the horizontal direction and in each of the map plane, bits are modified and substituted using the random number and random bit matrices being created. The technique failed to encrypt images with high resolution. Tiegang et al. [25] In the first part, total rearrangement of the image pixels is carried out whereas in the second part, encryption of the straggled image takes place using the hyper chaos. To transform the grey values of the image pixels, hyper chaos is used. This procedure had inefficient key space.

In the exhaustive literature survey, few parameters for good compression and encryption are as follow: high image quality is one of the most important criteria in a compression algorithm. Lossless compression of the multimedia data such as video, images, monochrome film and audio keeps all the data, but the compression algorithm must have high compression ratio because of the intrinsic information entropy of the data. The specialty of the compression algorithm also depends on the coding/decoding speed. Image compression algorithms must be nearly symmetric. Enhancement of the coding process and always encrypting the most vital information part of the data is very much necessary for a compression algorithm. Faster Encryption can be achieved in chaotic image encryption since it is time efficient. Thereby, making the process faster. Encryption techniques should have efficient key space in storing secret keys of the algorithm. Hence, it must not affect the execution efficiency. Encryption algorithms must be strong enough to be resistant to different security attacks in the communication channel thereby, ensuring no loss of information.

3. PROPOSED METHOD

In this paper, large satellite color images are compressed and encrypted using optimized JPEG-lossless compression and one-dimensional chaotic image encryption respectively. Compression is followed by encryption because encrypting large images in the first stage may seem complex due to execution overhead. Compression process ensures that the images are reduced in size considerably. Encryption process ensures that the compressed image is also secure and confidential when sent over a network channel. In this paper, optimized JPEG-lossless compression is used to compress the images in the first stage and one-dimensional chaotic image encryption is used to encrypt the compressed images in the second stage.

3.1 Optimized JPEG-Lossless Image Compression

This section describes the compression method based on the enhancement of JPEG-lossless compression technique. Image compression based on DCT [26] is optimized to compress images with large size and produce high quality reconstructed images. The methodology of the optimized JPEG-lossless compression is to choose a color source image of format like TIFF, JPEG or BMP from the user and compressing it to give a compressed file with maximum compression ratio. RGB color images are color space converted to $Y C_b C_r$ due to, human eye has different sensitivity to color and brightness. The color space conversion is followed by a conventional down-sampling approach. Down-sampling is replaced by sub-sampling technique to decrease the color resolution to lower bandwidth of the input space image effectively. Down sampling approach is to find the average of the pixels in a sampling area and then replace the entire sampling area with the average pixel values calculated at the specified resolution. Down sampling technique produces images of less smoothness and average reduction of size. Hence, there is a need for better sampling technique such as subsampling. Subsampling reduces the image size by removing information all together ensuring reduction of the image size horizontally and both vertically. The sub-sampling approach is found to be effective than the down-sampling technique. The process is followed by DCT and quantization stages to produce a compressed image file. The detailed process of the proposed methodology is discussed below. Figure 1 presents the optimized JPEG-lossless compression technique. Compression stage consists of four sequential steps, which takes high resolution satellite color image as input: RGB to YCC color space conversion, sub-sampling, DCT and quantization stage. Initially, a satellite color image is read to the compression algorithm. RGB color space of the input image is color space transformed to $Y C_b C_r$ - luminance and chrominance components shown in Figure 2.

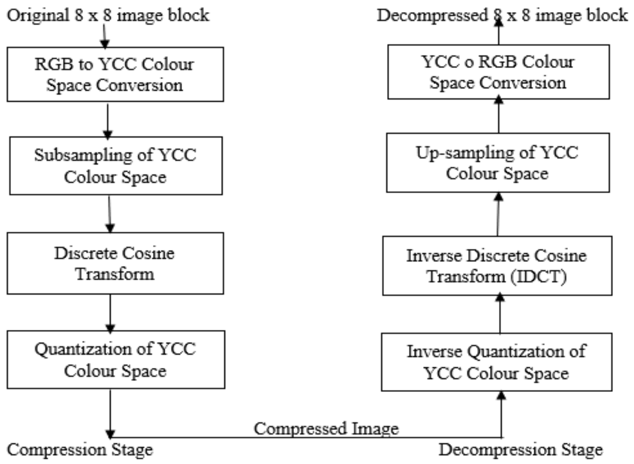

Figure-1: Optimized JPEG-lossless Compression

Color images are represented by three-pixel coefficients; they are red (R), green (G) and blue (B) components. This format is called RGB format. In this representation of the pixel with 3 bytes, one for each component. JPEG converts RGB color space to $Y C_b C_r$ color space because $Y C_b C_r$ tends to compress more tightly than RGB and is much easier than compressing the RGB image.

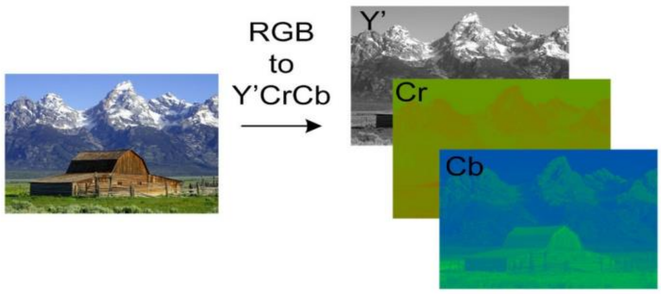

Figure-2: RGB to $Y C_b C_r$ color space conversion

Then, the subsampling technique is used to yield optimal sampling. The novelty is brought by choosing subsampling technique. Subsampling technique is to identify a pixel in the center of the sampling area and then replacing the complete area with the pixel being chosen at the resolution specified as shown in Figure 3.

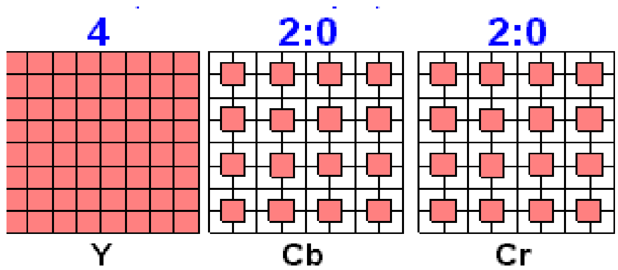

Figure-3: Subsampling of $Y C_b C_r$

This method decreases the conversion time as compared with down sampling but produces images of more smoothness and continuity. In a four by two dimension of array of image pixels, 4:2:2 has the half of the chroma values of 4:4:4, and 4:2:0 has less than half of the color chroma information. The 4:2:2 signals of the image will consist of half of the sampling rate in the horizontal direction, but it will maintain complete sampling rate in the vertical direction also. 4:2:0, on the other side, will only sample colors out of half of the image pixel values on the initial row and does not sample the second rows of the sample entirely.4:2:2 sub-sampling is ideal for color images. Next, the sampling technique is followed by DCT transform. DCT on the image blocks is performed in order to decrease the values of the pixels with high frequency. Then efficiently encode the resulting contents into a bit string. 8 x 8 image block is 64-point discrete signal which is a function of two spatial dimensions x and y. The 2D DCT is applied to each of these block images, and the output obtained is the basis signal amplitudes or 'DCT coefficients' shown in Figure 4. The coefficient with zero value at both the dimensions is called 'DC coefficient' which gives the average intensity of that block, and the remaining 63 coefficients are called 'AC coefficients'. The DCT equation is shown below in (1).

$$F(u,v)=\frac{2}{N}C(u)C(v)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)v}{2N}\right] \quad (1)$$

Where, C(u), C(v) = 1 / 2 for u, v = 0 ,C(u), C(v) = 1 otherwise and F(u, v) is the DCT coefficients. Finally, 8X8 block of DCT is now ready for quantization. Quantization is a technique of depicting larger image pixel values with a smaller set of image pixel values. Quantization stage is considered as a final stage of the image compression. In this stage, division of each DCT coefficient as a 'quantization coefficient' is significantly involved.

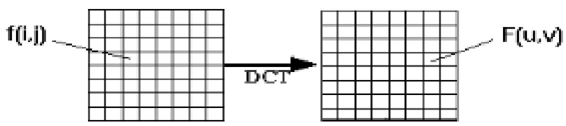

Figure-4: DCT of an image block

As the DCT values are represented less absolutely, dividing each DCT coefficient by a different quantization coefficient is mainly considered. The default quantization matrices of size 8x8 for luminance and chrominance quantization. The parameter to represent this division is called quantization step, always aims at decreasing the total bits necessary for compressing an image. Quantization step is given by formulae below.

$$F\ (u,v) = round\ (F\frac{u,v}{Q(u,v)}) \quad (2)$$

Where, F (u v) represents the DCT coefficient, Q (u v) is the quantization matrix and F^ (u v) denotes the quantized DCT coefficients.

Algorithm: Optimized JPEG-lossless image compression for large satellite images

Input: RGB satellite image I
Output: compressed image F^ (u, v)

Step 1: RGB to Y C_b C_r color space conversion,

$$Y = \left(\frac{77}{256}\right)R + \left(\frac{150}{256}\right)G + \left(\frac{29}{256}\right)B \quad (3)$$

$$Cb = -\left(\frac{44}{256}\right)R - \left(\frac{87}{256}\right)G + \left(\frac{131}{256}\right)B + 128 \quad (4)$$

$$Cr = \left(\frac{131}{256}\right)R + \left(\frac{110}{256}\right)G - \left(\frac{21}{256}\right)B + 128 \quad (5)$$

Where, Y C_b C_r are the luminance and chrominance color components of the image.

Step 2: Subsampling of chrominance components,

Cb (4:2:2, :)= [ ]; (6)

Cb (:, 4:2:2)= [ ]; (7)

Cr (4:2:2, :)= [ ]; (8)

Cr (:, 4:2:2)= [ ]; (9)

Where, C_b and C_r are the chrominance coefficients and – the C_B and Cr coefficients are each subsampled by a value of 2 horizontally and a value of 2 vertically denoted as 4:2:2 for optimal sampling rate in both horizontal and vertical direction.

Step 3: DCT of sub sampled image blocks are taken as:

$$F(u,v)=\frac{2}{N}C(u)C(v)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)v}{2N}\right] \quad (10)$$

For u = 0……N-1, and v = 0……. N-1. Where, N = 8 and C (k) = $1/\sqrt{2}$ for k = 0 or C (k) = 1 otherwise. F (u v) is the DCT coefficients.

Step 4: Quantization of DCT blocks:

$$F\ (u,v) = round\ (F\frac{u,v}{Q(u,v)}) \quad (11)$$

Where, F (u v) represents the DCT coefficient, Q (u v) is the quantization matrix and F^ (u v) denotes the quantized DCT coefficients. F^ (u, v) represents the compressed image. The compressed image is given to the effective chaotic image encryption algorithm.

3.2 One-Dimensional Chaotic Encryption

One-dimensional chaotic image encryption is used in the second encoding phase to encrypt the compressed images. In the algorithm of one-dimensional chaotic image encryption, the generation of logistic maps and cubic maps help to disorder the R G B color components of the image. The algorithm mainly useful in encryption of color images. Both logistic and the cubic maps perform separate functionality in the consecutive stages of the image encryption process. Initially, an RGB image or a grey scale image is given to the chaotic image encryption. The first step of the technique is the shuffling of blocks. Shuffling of blocks tends to divide the image in to N number of blocks and shuffle the image pixels according to the technique. Then, the shuffled blocks are row scrambled using the logistic maps. Logistic maps contain the information about the row scrambling operation, so that during the decryption process it is convenient to obtain the original values of the pixels. The row scrambling operation helps in the disordering the image pixels along the rows. In the next stage, the column scrambling process takes place along the columns to scramble the pixels of the image. Finally, the pixel diffusion stage is performed based on pixel permutation. Finally, all the pixels of the image are completely disordered. The encrypted image is evaluated for performance using three metrics such as UACI, NPCR and Information Entropy. The proposed algorithm for effective chaotic image encryption algorithm:

Algorithm: One Dimensional Chaotic Image Encryption
Input: Original Image, Parameters and Secret Chaotic Keys.

Result: Encoded Image.

Begin;

Step 1: Block shuffling of the image blocks separately.
Step 2: Row scrambling of the image blocks using the logistic maps.
Step 3: Column scrambling of the image blocks using the cubic maps.
Step 4: Pixel diffusion stage.
Step 5: Cipher image.
End;

4. RESULTS AND DISCUSSION

The implementation was carried out on the dataset consisting of 100 images captured by earth observation and remote sensing satellites, taken from Indian Space Research Organization (ISRO) Bengaluru. Images are in RGB color format and with horizontal and vertical resolution of 72 dots per inch (dpi). Images in the Dataset have high resolution and are large varying from 199 KB to 1.25 GB. Size of the dataset is 3.23GB. Images are in JPEG (joint photographic expert group), TIFF (tagged image file format) and Bitmap (BMP) image format. Results of the proposed work is the performance of compression and encryption.

4.1 COMPRESSION RESULTS

The proposed optimized JPEG-lossless compression and one-dimensional chaotic encryption algorithm has been tested using different satellite color images. The proposed scheme has successfully compressed the large satellite images as a first encoding phase. Then, the compressed images are encrypted using the one-dimensional chaotic image encryption algorithm in the second encoding phase. The image compression of the large satellite color images, its corresponding compressed, reconstructed images and the encrypted images are shown in Figure 5. The compressed images look black in color due to intense quantization. Encrypted images remain unrecognizable.

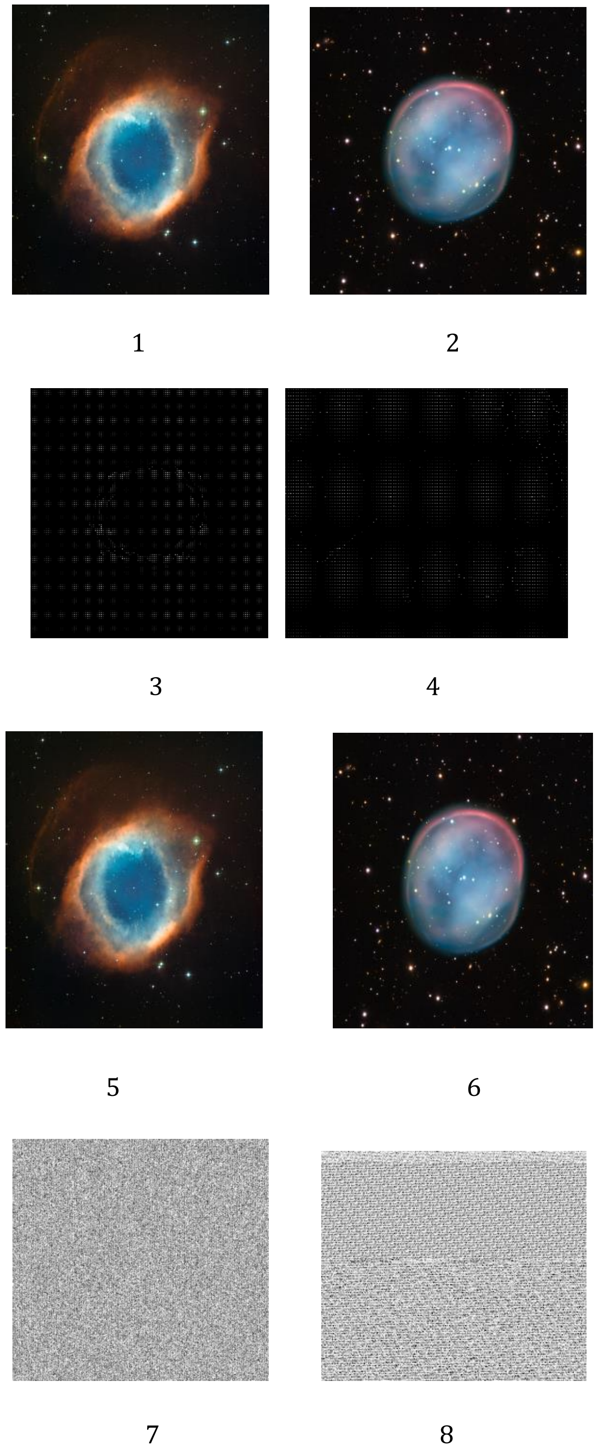

Figure 5: 1) Original satellite image of Helix Nebula, 2) Original satellite image of Planetary Nebula, 3) compressed image of Helix Nebula, 4) compressed image of Planetary Nebula, 5) Reconstructed image of Helix Nebula, 6) Reconstructed image of Planetary Nebula. 7) Encrypted image of Helix, 8) Encrypted image of Planetary Nebula.

Table 1 lists the image compression results of satellite images in comparison with standard DCT algorithm. Compression ratio, MSE and PSNR are the statistical measures of the performance evaluation of a compression algorithm. Compression ratio is the number of bits in the compressed image to the number of bits in the original image. MSE is the progressive squared error between the source image and the compressed image. PSNR is the measure of quality of the image reconstructed from the original image.

Table 1: Image Compression Results

Metrics	Optimized JPEG-lossless compression	Standard DCT based compression
Compression ratio	76%	56%
MSE	2.3811	4.6789
PSNR	55.3629 dB	39.9054 dB

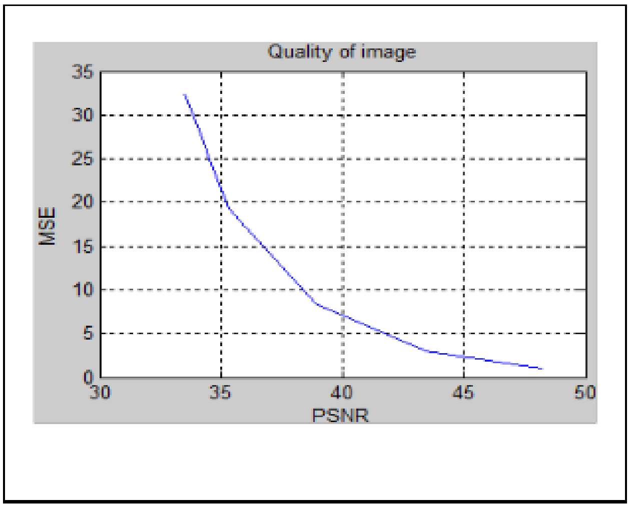

Chart-1: Graph showing PSNR and MSE analysis

Chart 1 presents a graph that shows a variation of quality of image with respect to PSNR and MSE values of image compression. PSNR and MSE values define the quality of the image being reconstructed. Image quality increases with increase in PSNR values and decreases with MSE values.

Linear curve in the graph denotes that the quality depends on both the values of PSNR and MSE. Quality is maintained with increase in PSNR and decrease in MSE. Chart 2 shows the comparison of PSNR analysis. PSNR values of enhanced JPEG-lossless compression technique is compared with DCT technique and JPEG-fuzzy technique for image compression performance evaluation. PSNR is considerably increased compared to both the techniques which yield good image quality of the image reconstructed.

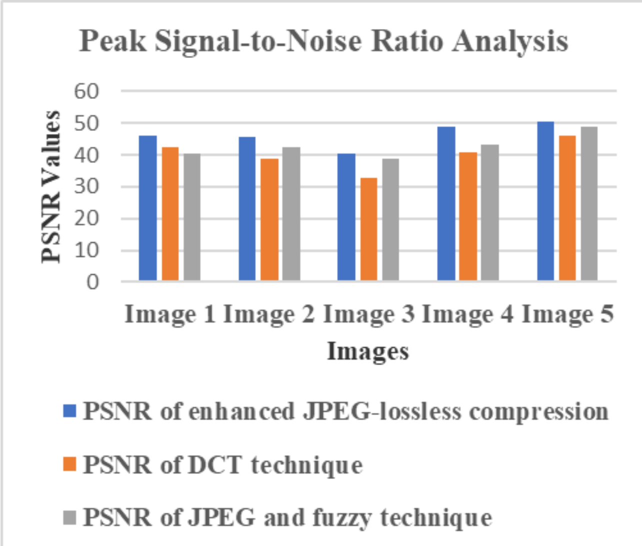

Chart-2: PSNR Comparison

Chart 3 shows the match of MSE analysis. MSE values of enhanced JPEG-lossless compression technique are compared with DCT technique and JPEG-fuzzy technique for image compression performance evaluation. MSE is a metric evaluated for mean residual error in the compressed image. MSE is considerably decreased compared to both the techniques which yields reconstructed image with less error factor. Less error indicates the accuracy of the reconstructed information

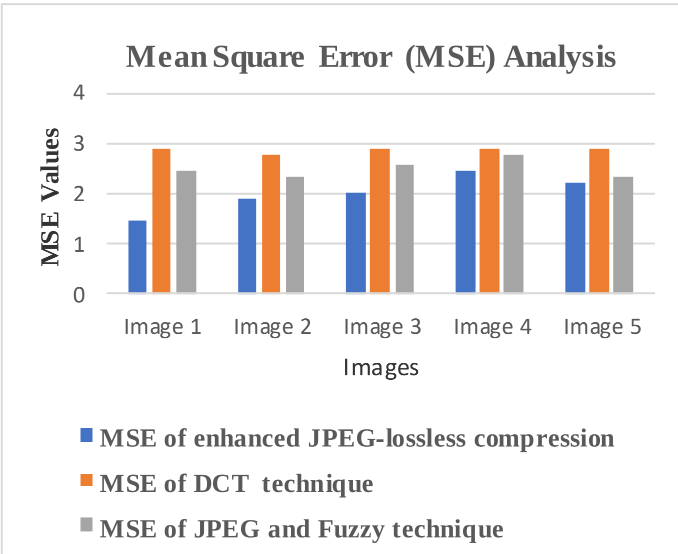

Chart-3: MSE Comparison

The metrics that measured encryption performance is given by number of pixels changing rate, information entropy and unified average changing intensity.

4.2 ENCRYPTION RESULTS

Table 2 shows the encryption results from the image encryption metrics. UACI, NPCR and the information entropy

(IE) values obtained are been tabulated. UACI is around 33.2%, NPCR is around 99.3% pixels change rate and information entropy of the cipher image is nearly equal to 8, the theoretical value that shows the cipher image has more random information. Entropy of the cipher image should always exceed the value of the entropy of the input image before encryption.

Chart 4 presents the correlation between UACI and NPCR of image encryption performance with respect to number of iterations of the encryption algorithm. UACI indicates the average changing intensity of the image blocks of the plain image. NPCR denotes the sum of image pixels change rate in the plain image. Both the metrics evaluate the degree of change of pixels in the original image. Number of iterations of the algorithms tends to increase NPCR values exponentially. Whereas, UACI values are decreased due to the average of values taken.

Table 2: Image encryption results

Metrics	1800 X 1800 pixels	4200 X 3012 pixels	4256 X 2832 pixels	5184 X 3456 pixels	14076 X3744 pixels
UACI	33.309	33.203	34.121	34.090	35.120
NPCR	99.36	99.398	99.272	99.504	99.268
IE	7.865	7.885	7.908	7.865	7.994

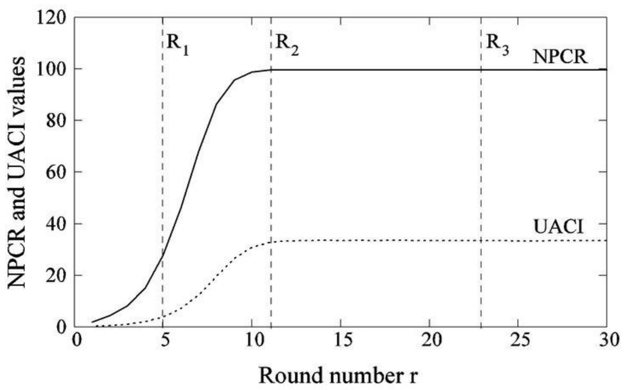

Chart-4: Graph showing NPCR and UACI correlation

ACKNOWLEDGEMENT

I am thankful to my guide, Associate Professor, Dr. Megha P Arakeri, Department of Information Science and Engineering for her constant support and valuable guidance. I also like to thank my parents, friends and above all, the almighty god for making this proposed work successfully complete.

5. CONCLUSIONS AND FUTURE SCOPE

In this paper, optimized JPEG-lossless compression algorithm and one-dimensional chaotic image encryption algorithm is used. The proposed optimized JPEG-lossless compression algorithm overcomes the issues of storage space requirements thereby, compressing the color images with high compression ratio. Compressed images are encrypted using the one-dimensional chaotic image encryption algorithm. **C**haotic image encryption solves the key space issue and degree of randomness. Performance of compression is measured by compression ratio of 76%, MSE calculated is average of 2% and PSNR is average of 56%. Performance of encryption is evaluated by UACI of **33.5**% and NPCR of 99.**3**%. Information entropy of the encrypted image is nearly equal to value of 8 that is the value proved theoretically, thereby showing high degree of randomness among image pixels. Since, the proposed compression system reconstructs the image with same high resolution as the original image, the compression is effective. The encrypted image is strong enough to defend brute force attacks to prove unbreakable encryption. Hence, it assists space image researchers for optimized satellite image communication with less bandwidth occupancy and security. In future this research may be carried out towards making automatic compression and encryption of large satellite images for a better and improved satellite communication that is secure and bandwidth constrained. The improved techniques can also be developed to reduce execution time overhead.

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