

A hybrid predictive technique for lossless image compression

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ABSTRACT

Compression of images is of great interest in applications where efficiency with respect to data storage or transmission bandwidth is sought. The rapid growth of social media and digital networks have given rise to huge amount of image data being accessed and exchanged daily. However, the larger the image size, the longer it takes to transmit and archive. In other words, high quality images require huge amount of transmission bandwidth and storage space. Suitable image compression can help in reducing the image size and improving transmission speed. Lossless image compression is especially crucial in fields such as remote sensing healthcare network, security and military applications as the quality of images needs to be maintained to avoid any errors during analysis or diagnosis. In this paper, a hybrid prediction lossless image compression algorithm is proposed to address these issues. The algorithm is achieved by combining predictive Differential Pulse Code Modulation (DPCM) and Integer Wavelet Transform (IWT). Entropy and compression ratio calculation are used to analyze the performance of the designed coding. The analysis shows that the best hybrid predictive algorithm is the sequence of DPCM-IWT-Huffman which has bits sizes reduced by 36%, 48%, 34% and 13% for tested images of Lena, Cameraman, Pepper and Baboon, respectively.

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1. INTRODUCTION

In today's modern era, multimedia communication has become a norm and gives a huge impact on human's lives. There is a tremendous amount of image data being shared and accessed on social media networks such as Facebook, Twitter and Instagram. In addition, due to the Industry Revolution 4.0 and Internet-of-Things (IoT) technology, the trend of exchanging and controlling almost everything wirelessly is likely to continue far into the future. Even though storage costs are decreasing, the volume of digital image data to be transmitted and stored is increasing at a much faster rate. It is also more susceptible to noise during transmission. Image compression technique can be deployed in order to promote faster transmission speed and reliable data transmission. However, quality images are very crucial for fields like military applications, healthcare and biometric-based security solutions using fingerprint or face recognition. Due to its noiseless characteristic, lossless image compression is beneficial when it comes to handling image that must maintain its quality and original form.

High compression ratio and the ability to decode the compressed image's data at various resolutions is necessary for a compression process [1]. The image is compressed by reducing the spatial and spectral redundancy so that the image can be stored and transmitted in a proper manner [2]. By performing image compression, a large size of image data can be managed and stored efficiently with the use of suitable

technique. Image compression can increase the amount of the storage space by encoding the original image with limited bits. The transmission time to upload a compressed image on the internet and get a download from the webpages becomes shorter. If there is a loss of data during compression, it will lead to the problem during analyzing the data as the resulted analysis is not precise. Therefore, there is a need to develop a good image compression technique that is almost error free and can produce a reconstructed image that as true to its original form as possible.

There is a lot of research works that has been conducted in lossless image compression. Some of the common lossless image compression are LZW, DEFLATE, LOCO-I, JPEG-LS, run-length encoding JPEG, JPEG 2000 and etc [3-25]. According to Amira Mofreh et.al, combining Linear Predictive Coding with Discrete Wavelet Transform and-Huffman (LPCDH) gives faster and higher compression ratio compared to DWT-Huffman [22]. C Jain, V Chaudhary, K Jain et.al has proposed a different method based on lossless image compression where it uses Wavelet Packet Transform (WPT) followed by lifting scheme [23]. Based on their analysis, Integer Wavelet Packet Transform (IWPT) speed up the decomposition process and gives high compression ratio compared to WPT. The other proposed method of lossless image compression is performed by Vineeta G. A.G. Rao and K. Mohan Pandey where they proposed Integer wavelet transform as a predictive method [25]. The resulted studies show that they achieved maximum compression ratio when the coefficient is added and varies in lifting scheme. The proposed method proves that predictive Integer wavelet transforms with coefficient gives high compression ratio compared to Integer Wavelet Transform (IWT) without coefficient.

This paper focuses on developing an algorithm for hybrid predictive coding by combining predictive Differential Pulse Code Modulation (DPCM) and IWT. The performance of DPCM-IWT and IWT-DPCM is compared and the best hybrid predictive coding will be chosen to be combined with Huffman entropy coding for further compression process. Several tables of truncated Huffman have been designed in order to achieve maximum compression ratio. Five grayscale images have been used to test the compression engine. The image compression engine is done by designing the MATLAB code by using MATLAB software model. The remainder of this paper is organized as follows. The background and the methodology of the lossless compression techniques are presented in Section 2. Then, Section 3 discusses the results. Lastly, the conclusion is drawn in Section 4.

2. LOSSLESS IMAGE COMPRESSION TECHNIQUES

Traditional transform-based methods for compression, while effective, are lossy. In certain applications, such as biomedical image analysis, even slight compression losses can be unacceptable. Therefore recent research has focused on finding more efficient ways of achieving *lossless* compression; i.e., the process of compressing images without any degradation in quality or any quantization losses. This section discusses the methodology that is used to achieve lossless image compression. Basically, the proposed lossless image compression is constructed by combining predictive coding and entropy coding. As for predictive coding, it is performed by combining two types of predictive coding which are IWT and DPCM where the pixels are predicted through these predictive codings. After the pixel is predicted, the image is further compressed with entropy coding.

The basic step and flowchart for the proposed work are given as follows. The first step is to read the image. Next, DPCM encoder is performed where the pixels are read by column and row and predict the pixel. DPCM exploits the inter-plane correlation by producing a difference matrix with an average value much smaller than the average value of the original image. It reduces the number of binary 1s in the more significant bit planes, and therefore increases compression because run-length encoding will have fewer groups of binary 1s to encode. This is followed by IWT encoder by applying lifting scheme and Haar wavelet transform. The output of IWT will be converted to positive integer. Next step is to calculate the frequency occurrence symbol and calculate the entropy. Then, the pixel distribution is computed followed by a display of the distribution graph of hybrid predictive coding.

The positive integer is then converted into 1-dimension (1D) before Huffman compression is performed based on the designed Huffman truncated table. Next, the entropy value of the compression images is computed based on the resulted codeword. Lastly, the compressed codeword is decoded in order to recover the original images. Figure 1 shows the block diagram of the proposed lossless image compression.

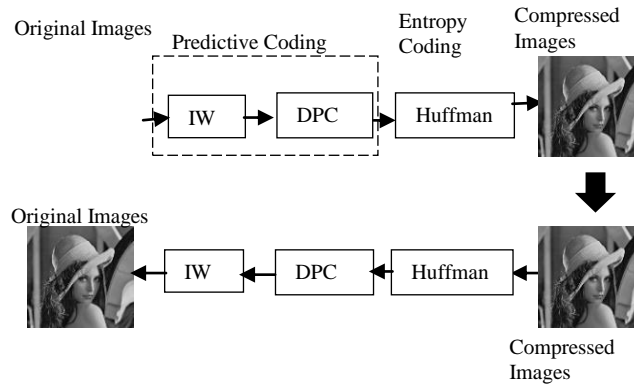


Figure 1. Block diagram of the proposed lossless image compression

2.1. Different Pulse Code Modulations (DPCM)

DPCM is one of the proposed predictive coding techniques. DPCM prediction is nonlinear. Its basic idea is to predict the information in every image pixel and make the predicted image entropy less than the original image entropy. Because there is strong correlation among adjacent pixels, current pixel values are predicted by pixel knowledge. It works by predicting the pixels value where the pixel error will be the resulted output. Pixel error is obtained by subtracting the original pixel with the predicted pixel value. The resulted pixel error will have a lower zero-order and concentrated near to zero. The DPCM algorithm was designed by using the formula in (1).

$$PixErr_{(x,y)} = Im_{(x,y)} - [k1(Im_{(x-1,y)}) + k2(Im_{(x,y-1)}) - k3(Im_{(x,-1y-1)})] \tag{1}$$

Figure 2 and 3 depict the original pixel and the obtained pixel error, respectively.

96	97	95	97	102	106	107	108
123	99	97	100	109	117	120	122
103	104	110	116	118	117	116	117
109	108	110	108	102	105	118	133
109	103	108	109	112	125	140	143
100	113	115	129	136	131	141	146
114	103	110	129	139	132	139	149
112	94	90	99	115	123	134	141

Figure 2. Original pixel value

0	1	-2	2	5	4	1	1
27	-11	-1	2	7	10	8	8
-8	4	9	9	4	-2	-3	-2
6	0	-1	-6	-11	-5	8	16
1	-6	2	3	6	14	15	7
-6	10	4	16	12	-4	5	4
8	-11	-3	8	8	-6	2	7
4	-15	-17	-13	-2	-3	1	-1

Figure 3. Pixel error

2.2. Integer Wavelet Transform (IWT)

IWT is the other predictive coding that is used in this proposed method. By performing IWT, it can map integer to integer where it requires shorter data length compared to floating point. Integer wavelet transforms was developed by Win Sweldens where it was designed based on lifting scheme [23].

Lifting scheme allows IWT to compute faster since it produces integer number. By performing IWT, it allows performing reversible image compression [23]. Lifting scheme is done by applying Haar wavelet

transform as mother wavelet because it is easy to compute and simple. IWT is constructed based on three basic steps which are split, predict and update [23-25].

By applying lifting scheme into IWT, it will result in image decomposition where the image is sub-sampled into parts where the resolution is decreased from one level to the next level until the desired resolution is achieved as shown in Figure 4 [23].

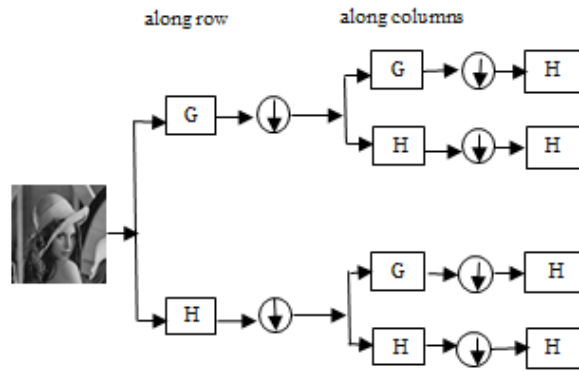


Figure 4. Image decomposition by applying lifting scheme

The image is filtered by using high pass filter (G) and low pass filter (H). It starts by filtering the row parts followed by the column parts. The images are then down-sampled by 2 to produce high and low-frequency components. Different sub-bands are produced during IWT encoding where it consists of one approximation and three details where LL (approximation sub-band), HL (horizontal sub-band), LH (vertical sub-band) and HH (diagonal sub-band) are resulted from the first level decomposition and second stage of filtering. This is shown in Figure 5.

LL	HL _n	HL2	HL1
LH _n	HH _n		
LH2		HH2	HH2
LH2			

Figure 5. Multiresolution scheme after several levels of wavelet

2.3. Entropy coding

Entropy coding is used as a compression part in lossless image compression. Entropy coding or run-length encoding produces compression by replacing a sequence of binary data with a sequence of hexadecimal numbers, each of which represents the number of occurrences of the same binary value in an unbroken string. The simplest entropy coding is a static Huffman truncated table. Although dynamic Huffman coding will produce better compression than static coding (because the dynamic code is specially customized to the data), this superior performance is impacted severely by the need to include the code key as a table along with the header data. Because there is the almost certain probability that the code key will be different for every bit plane and every image block, the header penalty would be too great.

A Huffman truncated table has been constructed where it consists of tail and head where it was designed based on the pixels frequency occurrence produced from the hybrid predictive coding. The truncated Huffman coding can cover up to 512 number of symbols. The output of predictive coding will be converted to the positive integer and then will be compressed by Huffman truncated coding. A codeword is

produced after compression process where head and tail are concatenated together. The pixels that have the highest probability will be assigned to the shortest codeword based on the generated pixel distribution graph. The produced codeword contains lesser bits compared to the original bits.

3. RESULTS AND ANALYSIS

The results are obtained from the implementation of the proposed method as provided on the block diagram in section 3. The performance of the proposed hybrid predictive method was analyzed by conducting image compression by using two different methods. For the first method, hybrid predictive IWT-DPCM was performed. For the second method, hybrid predictive DPCM-IWT was performed on the same image and the resulted compression ratio is calculated on both methods to observe which method is the best hybrid predictive algorithm. The input image that is used for testing is in BMP format and the image resolution is 512x512. The designed algorithm has been tested on a set of 5 grey images with the same format and size as shown in Figure 6. This test image is a well known standard test image used by most established methods. Since current image sensors use higher resolution, this result for 512x512 image will be useful to satisfy the higher resolution image requirement.

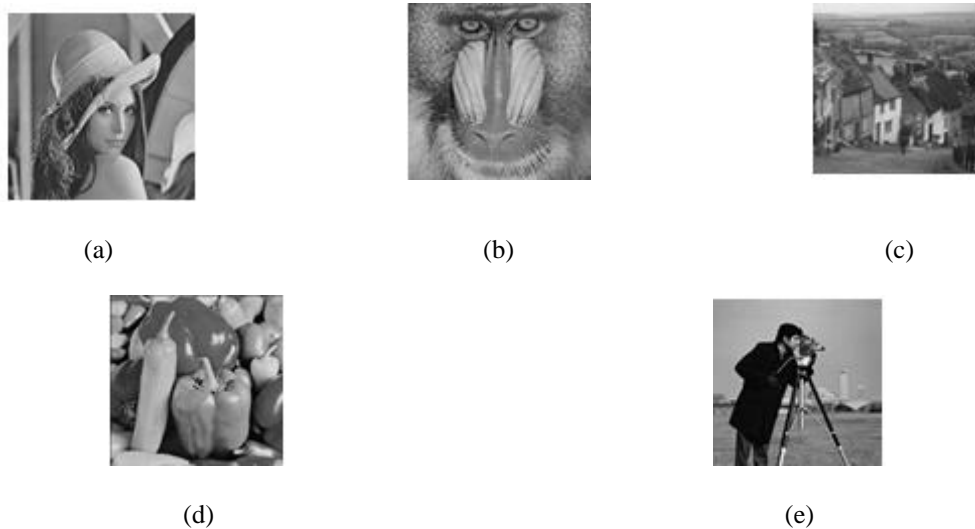


Figure 6. Original images, (a) Lena, (b) Baboon, (c) Goldhill, (d) Peppers, (e) Cameraman

Table 1 shows the comparison of entropy for the two methods which are IWT-DPCM and DPCM-IWT, respectively. Most established methods didn't provide entropy for predictor. Main objective from this paper is to find the best combination between DPCM and IWT. Based on the table, the entropy value of method 2 is lesser than method 1. The cut-off pixel distribution graph that has been calculated in every picture shows that most of the image is having a high probability of pixels around the range of -50 to 50. Therefore, less codeword of Huffman truncated table is assigned to the pixels in between the range of -50 and 50 to achieve maximum compression ratio.

Table 1. Entropy comparison

Images	Predictive method	
	Method 1 (IWT-DPCM)	Method 2 (DPCM-IWT)
Lena	4.8954	4.7555
Baboon	6.4361	6.3424
Goldhill	5.0319	5.5163
Peppers	5.0009	4.9787
Cameraman	3.7192	3.5825

The criterion used to compare the performance is the ratio of the quantity of size reduction (with respect to the number of bytes) of the original file, given by;

$$\text{Compression Ratio} = (\text{Original File Size} - \text{Compressed File Size}) / \text{Original File Size} \quad (2)$$

Table 2 shows the comparison of compression ratio resulted after the image has been encoded by Huffman. Some established methods using bit reduction to show their result. Since, many of them using compression ratio unit, so we use it as a standard comparison. It shows that most of the images give high compression ratio by applying method 2 compared to method 1.

Table 2. Compression ratio comparison

Images	Predictive method	
	Method 1 (IWT-DPCM)	Method 2 (DPCM-IWT)
Lena	1.4999	1.5457
Baboon	1.0258	1.0522
Goldhill	1.3181	1.2576
Peppers	1.4471	1.4644
Cameraman	2.0469	2.1214

The perfect reconstruction of images is clarified by displaying the original picture in Figure 7 with the picture that has been decoded in Figure 8. The difference of the reconstructed image and the original image will give black image since all the pixels will become 0 as there is no error in the reconstructed image.

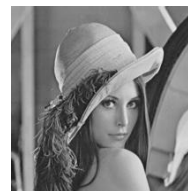
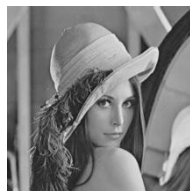


Figure 7. Original image

Figure 8. Reconstruct image

The performance of hybrid predictive between the proposed methods has been compared by calculating the entropy value and compression ratio. From the analysis, it can be concluded that DPCM-IWT is a better hybrid predictive method as it produces lower entropy value and compression ratio. The number of bits of Lena is reduced by 36%, Cameraman is reduced by 48%, Peppers is reduced by 34% and Baboon is reduced by 13% after applying hybrid predictive of DPCM-IWT. The truncated Huffman table that has been designed is applicable to be used for the tested image as most of the image is having the same cut-off pixel distribution and the design of Huffman truncated table is flexible to be used in any image as the codeword could be assigned in any symbol manually. By implementing hybrid predictive of DPCM-IWT through the lossless image compression, it contributes to optimized performance of lossless image compression field.

4. CONCLUSION

It is found that the combination of predictive DPCM and IWT could improve the performance of predictive coding of lossless image compression. The resulted analysis found that to achieve maximum compression of hybrid predictive coding, the resulted approximation sub-band that is encoded by IWT needs to be encoded with DPCM. From the analysis, the hybrid predictive technique with sequence DPCM-IWT-Huffman performs better with lower entropy and compression ratio. The perfect reconstruction of the image is clarified by comparing the difference between constructed image and the original image. The resulted black image of the difference has proven that there is no loss for the predicted pixel. In summary, the proposed hybrid predictive technique for lossless image compression is a promising solution to achieve faster transmission speed and lower storage space for image transmission over telecommunication network for applications such as healthcare network and biometric security solution.

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