PERFORMANCE ENHANCEMENT OF HUFFMAN CODING IMAGE COMPRESSION WITH CHINESE REMAINDER THEOREM

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ABSTRACT: Data compression is the process of reducing the size of data. Due to the improvement of Information Technology, there are more data that are being generated nowadays that are transferred from one source to another. This data required higher size and bandwidth to be transferred between two parties. Hence, how to reduce the size of data before transferring from one medium to another has been an important issue. This paper proposed an enhanced method to compress image data file. In this paper, we integrate Chinese Remainder Theorem (CRT) into the Huffman compression algorithm to enhance the speed of compression as against the Traditional Huffman Compression (THC). The experimental analysis was performed in matrix laboratory environment (2015). The experimental results revealed that there is significant reduction in size of image, compression time minimization and data quality retention of original image. The shortcomings of THC are blocky appearance and poor quality reconstructed image after decompressing operation is overcome in our enhanced method with CRT
KEYWORDS: Huffman Algorithm, Chinese Remainder Theorem (CRT), compression, Image File

1. INTRODUCTION

A number of scholars have highlighted efforts in energy reductions during data transmission using the data compression approaches. These concepts are generally based on increasing compression ratio of resultant data, which in turn decreasing the energy [JK16]. Media data content have been known to contain huge redundancy and irrelevance, which make them unsuitable for storage, applications, transmission. Data compression schemes have been applied to the fields of Wireless Sensor Networks, medical imagery, and other fields of digital data transmission [AAA18]. There are several studies that have considered efficiency of data compression processes for different types of data including text, images, videos and others. Huffman coding is one of the widely used compression algorithms, whose outcomes showed considerable size reduction at average of 43% for media such image [JK16]. There is need to drive this performance higher with increased compression rate, decreased size of media, and computational time savings [TR18]. Most importantly, lossless compression algorithms such as Huffman coding provide sufficiently good quality and compression rates for images but, blocky appearance for reconstructed images [OS18]. This work employs Chinese Remainder Theorem (CRT) into the compression procedure of Huffman coding for the purpose of achieving improved efficiency of resulting compressed media such as image, even after reconstruction.

2. RELATED STUDIES

A study to enhance the performance of Huffman coding with LZ coding for image data compression was proposed by [SS13]. This is achieved by a lossless compression approach referred to as HL (Huffman and Lempel), which is made up of Huffman compression of image to produce codewords. These were compressed further with LZ with high quality in terms of parameters used. Compression time was not deployed during the procedure.
Enhancing information compression and safety using LZW-RNS technique was proposed by [AGB15]. The LZW algorithm was amplified by RNS because it became feasible to convert data other forms. These processes led to reduction in CPU time for compression, and improved storage capacity, faster compression and transmission of data over the traditional LZW scheme. In effect, this work offered more insights into the application of Residue Number System.
The possibility of improving stream processes was experimented with data compression approach [P+18]. There is new capability to effect larger windows processes and throughputs of executions. Consequently, direct execution on compressed textual data showed significant benefits for memory, throughputs and latency in transmission.

2.1 HUFFMAN ENCODING

Huffman coding is an entropy encoding algorithm used for lossless image compression. Huffman coding is efficient technique for image compression to some extent [PK10]. The Huffman encoding starts with calculating the probability of each symbol in the image. The symbols probabilities are arranged in a descending order forming leaf nodes of a tree. When the symbols are coded individually, the Huffman code is designed by merging the lowest probable symbols and this process is repeated until only two probabilities of two compound symbols are left. Thus, a code tree is generated and Huffman codes are obtained from labelling of the code tree [Huf52]. Figure 1 shows a schematic block diagram for image compression using Huffman encoding method [A+15].

The minimal length binary code for a two-symbol source, is the symbols 0 and 1. The Huffman codes for the symbols are obtained by reading the branch digits sequentially from the root node to the respective terminal node or leaf. Huffman coding is the most popular technique for removing coding redundancy as shown in Fig. 2 [PK10]. Huffman code procedure is based on the following two observations:

1) More frequently occurred symbols will have shorter code words than symbol that occur less frequently;
2) The two symbols that occur least frequently will have the same length.

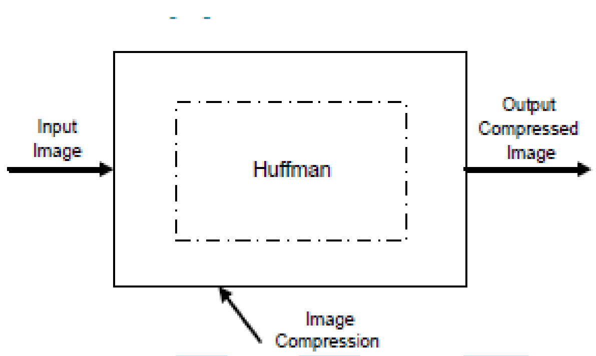

Fig. 1: Huffman encoding based image compression procedure [A+15]

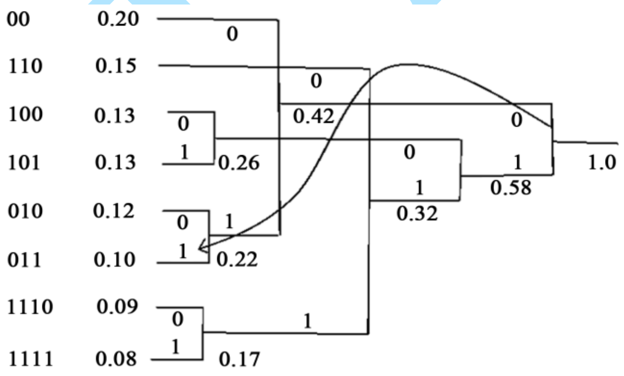

Fig. 2: Huffman encoding procedure [PK10]

The average length of the code is given by the average of the product of probability of the symbol and number of bits used to encode it [GVS13] and [M+13]. The Huffman code efficiency is calculated as:

Huffman code efficiency = entropy / the average length.

Huffman's procedure creates the optimal code for a set of symbols and probabilities subject to the constraint that the symbols be coded one at a time [PK10].

2.2 CHINESE REMAINDER THEOREM

The operation of traditional Chinese Remainder Theorem (CRT) is to generate a single integer by means of its residue modulo within moduli set. There are widespread application in area of error correction, estimation of frequency of under sampled waveforms, phase unwrapping, wireless sensor networks, modular multiplication computing and others [X+18]. CRT is an alternative to the Mixed Radix Conversion (MRC) where the large modulo M calculations is not required. MRC accepts a low complexity of 0(n) as compared to the CRT whose computation complexity of order $0(n^3)$. Thus, in CRT, arithmetic operations for modulo M are to be performed. CRT residue converters are much more complex. In contrast, the MRC procedure requires arithmetic operations for modulo m_i only, thereby making all operations simpler as compared to CRT. In MRC method, a number x is expressed in mixed-radix system. Suppose for moduli set $(m_1, m_2, \dots, m_n)$, RNS representation of a number x is given as $(x_1, x_2, \dots, x_3)$. The number x can be expressed in mixed-radix form as:

$$|x|_{m_1} = a_1$$

$$X = a_n \prod_{i=1}^{n-1} m_1 + \cdots a_3 m_1 m_2 + a_2 m_1 + a_1 \quad (1)$$

where, the a_i's are the mixed-radix coefficients. These a_i's are determined sequentially, starting with a_1, in the following manner:

Equation (1) is first taken in modulo m_1. Since all terms except the last are multiples of m_1, we have

$$|x|_{m_1} = a_1$$

Hence, a_1 is just the first residue digit. To obtain a_2, first we subtract a_1 from x. The quantity x-a_1 is divided by m_1, and doing modulo operation with respect to m_2, we have

$$\left|\frac{|x - a_1|}{m_1}\right|_{m_2} = a_2$$

Similarly, for a_3, $(a_2 m_1 + a_1)$ is subtracted from x. By dividing the quantity $(x - a_2 m_1 - a_1)$ by $m_1 m_2$ and performing modulo operation with respect to m_3, we get

$$\left|\frac{|x - a_2 m_1 - a_1|}{m_1 m_2}\right|_{m_2} = a_3$$

In this way, by successive subtraction and division in residue notation, all the mixed-radix digits may be obtained.
Conversely, an RNS number $(x_1, x_2, x_3 \ldots . x_k)$ for the moduli set $(m_1, m_2, m_3 \ldots . m_k)$ whose decimal equivalent is given by:

$$a_1 = x_1 \quad (2)$$
$$a_2 = \left|(x_2 - a_1)|m_1^{-1}|_{m_2}\right|_{m_2} \quad (3)$$
$$a_3 = \left|\left((x_3 - a_1)\left|m_1^{-1}\right|_{m_3} - a_2\right)\left|m_2^{-1}\right|_{m_3}\right|_{m_3} \quad (4)$$

Therefore, a general expression is given by:

$$a_3 = \left|\left(\left((x_n - a_1)\right|m_1^{-1}\left|_{m_n} - a_2\right)|m_2^{-1}\right|_{m_n} - \cdots - a_{n-1})|m_{n-1}^{-1}\left|_{m_n}\right|_{m_n} \quad (5)$$

The mixed radix digit (MRD) of a_i, $0 \le a_i \le m_i$, any positive number in the interval by $[0, \prod_{i-1}^{k} m_i - 1]$ can be uniquely represented. The major advantage of MRC, as can be seen from equation (5) above is that the calculation of $a_i; i = 1,$ k can be done only using arithmetic mod-m_i contrasting CRT, which entails arithmetic mod-M, M being the system dynamic range, a rather large constant. It can be noted that equations (2) and (3) are directly utilized, only if the moduli set $\{m_1 m_2 m_3 \ldots m_k\}$ are relatively prime and that Euclidean algorithm is the common way to verify this, i.e., if $\gcd(m_i, m_j) = 1$, for $i \neq j$.
The residue independence, carry-free operation and parallelism features of the RNS, has been intensively used in many areas, such as digital signal processing (DSP), digital filtering, digital communications, cryptography, error detection and correction [OP07] [Moh02]. Moreover, the attraction to utilize RNS in low-power design has arisen. This is of great benefit in areas where addition, subtraction and multiplication are dominant and division, comparison, overflow and sign detection are minor. Hence, the RNS has become a tough candidate for high-performance, fault tolerant and secure DSP applications. One main area for RNS-based applications is finite impulse response (FIR) filters. Trends to use the RNS for reducing power consumption have also appeared to be feasible. Similarly, digital image processing is another area benefiting of the RNS's features. Many researches were dedicated for exploiting the RNS features for enhancing digital image processing applications. In addition, error detection and correction applications greatly benefit from the RNS's features. Also, due to the carry-free and the lack of weighted significance of residue digits' properties, an error in a digit does not propagate, hence, does not affect other digits. This system uses redundant moduli, thus, errors can be precisely detected and corrected. In this system, the dynamic range is divided into two intervals; the legitimate range and illegitimate range. A single-digit error is detected if the binary result after reverse conversion belongs to the illegitimate range. In order to detect a single-digit error, a single redundant modulo is sufficient. On the other hand, in order to detect and correct a single-digit error, at least two redundant moduli should be utilized [OB07]. Also, RNS has been utilized in communication for many purposes, such as parallel transmitting a set of orthogonal signals and direct sequence spread spectrum. Finally, cryptography is another area where RNS can be efficiently utilized. The major usage of the RNS is with RSA (Rivest, Shamir and Adleman) algorithm.

3. METHODOLOGY

This study utilizes lossless compression approach on sample images to demonstrate the compression procedure of Huffman coding and CRT. The structure of the proposed compression scheme is presented in Fig. 3.

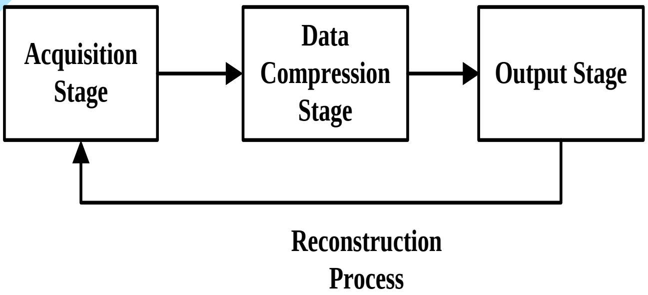

Fig. 3. The structure of the proposed data compression scheme

The acquisition stage is analogous of the input component because it is concerned with accepting diverse images formats for the entire process of data compression. The original forms of images are entered into the system awaiting removal of irrelevance and redundancy. The data compression stage undertakes two operations; the first is the compression of original image using the Huffman coding scheme. The second operation applies CRT computation to the resulting image to obtain enhanced and compressed image. The output stage produces the compressed format of original image acquired with minimal redundancy and irrelevance as compared to original images.

The performance metrics used for this study include:
Compression ratio: It is the uncompressed data size divided by compressed data size.
Compression time: It measures the rate of compressing data bits within a fraction of time (per second).
Peak Signal to Noise Ratio: This is used to determine the level of noise in the signals of compressed data against original data.
The operational algorithm of proposed compression scheme is given as follows:

I. Read the input to the MATLAB simulator workspace.
II. Enhance image outlooks and dimensions to fit appropriate into viewer.
III. Run Huffman coding function in order to find symbols of the pixel values.
IV. The probability of pixel symbols are organized in decreasing magnitude and smaller probabilities are combined.
V. The Huffman codeword is concatenated before applying CRT.
VI. The moduli set is chosen to obtain the best redundancy in data.
VII. The compressed image data is attained as final encoded values.
VIII. The reconstruction can be obtained by applying decoding of Huffman and CRT.
IX. Reconstructed image data is realized.

4.0 RESULTS AND DISCUSSION

The experimentation of the proposed image data compression using the CRT and Huffman coding for 10 pictures sampled are into phase. The first phase is analogous to the conventional Huffman coding, while the second phase combines the compression procedures of CRT and Huffman coding as presented in Table 1.

Table 1. Data compression of Huffman coding without CRT

Image sample	Size before compres-sion	Size after compres-sion	Compres-sion time	PSNR	Compres-sion ratio (%)
1	12282	1853	33.70	28.29	4.13
2	12906	1819	33.38	28.34	4.14
3	12353	1745	31.81	27.73	4.28
4	12762	1766	33.38	28.27	4.15
5	12872	1854	33.54	27.85	4.02
6	12357	1783	32.96	28.29	4.28
7	12150	1593	30.29	28.22	4.92
8	12243	1638	31.48	28.07	4.59
9	12530	1614	32.05	28.10	4.63
10	12319	1672	31.27	28.09	4.65

In Table 1, the average reduction in sizes of original image and compressed images revealed ratio of 1:7 and averaging at 12477.4 kb and 1733.7 kb respectively. This implies that the sizes of compressed images are seven times smaller than original images. The PSNR and compression ratio are relatively stable for the 10 samples of image experimented averaging at 28.13 and 4.38 respectively. It can be attributed to presence of redundancy and irrelevance in the resulting images. The outcomes of further image data compression with CRT are presented in Table 2.

Table 2. Data compression of Huffman coding with CRT

Image sample	Size before compres-sion	Size after compres-sion	Compres-sion time	PSNR	Compres-sion ratio (%)
1	12282	1853	18.40	28.29	4.13
2	12906	1819	18.35	28.34	4.14
3	12353	1745	16.86	27.73	4.28
4	12762	1766	18.56	28.27	4.15
5	12872	1854	21.05	27.85	4.02
6	12357	1783	18.02	28.29	4.28
7	12150	1593	14.91	28.22	4.92
8	12243	1638	31.48	28.07	4.59
9	12530	1614	17.53	28.10	4.63
10	12319	1672	16.37	28.09	4.65

In Table 2, the parameters for evaluating the performance of data compression procedure with CRT and Huffman coding revealed similar characteristics for the image size, PSNR and compression ratio. However, the compression time using the CRT reduced significantly on the average as 32.39s and 17.74s respectively. The quality of compressed image data remained unchanged using CRT, the reason being that the computation overhead incurred in Huffman coding was minimized leading to speedy compression (or removal of redundancy). Again, the reconstruction of original images compressed with CRT-Huffman coding was better than Huffman coding alone as shown in Fig. 4.

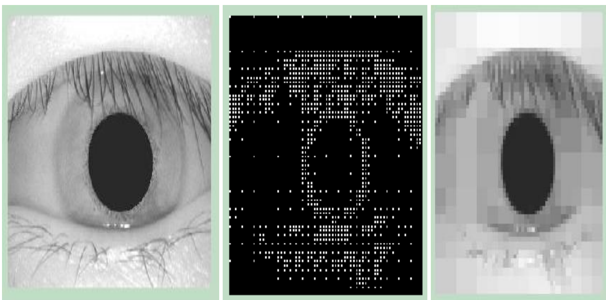

Fig. 4. Original and reconstructed images for Huffman-CRT

In Fig. 4, the first image is the original sample image before applying the Huffman and CRT coding. The middle image is the outcome of applying Huffman coding, which is typically poor as compared to the original image. The last image is output of enhancing traditional Huffman coding compression with CRT that revealed better outlook when compared to the original image and Huffman reconstructed image. This study benchmarked with [AAA18], which indicated that image compression using Huffman Encoding alone offered 25.59 PSNR averagely against 28.13 obtained in this paper. This implies that, the quality of reconstructed images using CRT with Huffman coding is most desirable.

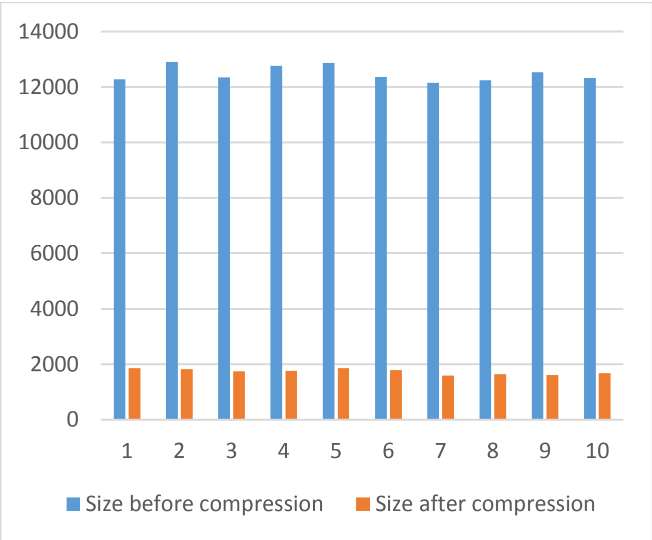

Fig. 5. Image size for Huffman Algorithm before and after compression with and without CRT

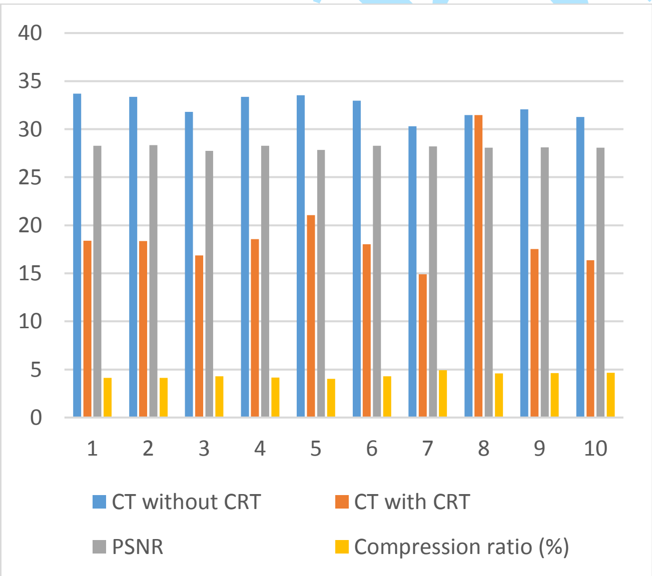

Fig. 6. Parameters used with Huffman with and without CRT (CT= Compression time, PSNR= Peak Signal to Noise Ratio)

Fig. 5 shows the sizes of the images before and after compression using Huffman algorithm with and without CRT without any reduction in their kilobytes.

In Fig. 6, it shows that there is a significant reduction in the compression time when compared with and without CRT but stability with that of the PSNR and Compression ratio.

5. CONCLUSION

Images have been deployed for diverse applications, though large bits composition stands in the ways of widespread and sensitive usages. This paper revealed that Huffman coding procedure on images turn out to be fast, with enormous size decrease, but falls short during reconstruction into original image. To deal with this, CRT was used with Huffman coding with significant performance improvement over the traditional Huffman based data compression using PSNR, compression time, and size. The future work would be to investigate the effect of CRT on another compression algorithm like Lempel-Ziv-Weich (LZW).

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