Lossless color image compression using double level RCT in BBWCA

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Abstract

A new lossless image compression scheme for natural color images which is based on double level Reversible Color Transform(RCT) and Bi-level Burrows Wheeler Compression Algorithm(BBWCA) is proposed. The first level RCT from RGB to HSV provide higher reduction in number of unique hue components, thus gives higher compression in case of natural images. The first level RCT followed by the second level RCT from HSV to YUV helps to yield small number of unique Y component values. DC level shifting and twos complement operation will be applied as preprocessing steps to second level RCT. The result of double level RCT is used as the input to BBWCA, in which row-wise BWT followed by column-wise BWT is applied. The compressed image data is formed by using move-to-front(MTF), Run-length-encoding and Entropy coding. The proposed method using double level RCT with BBWCA results in high compression by taking advantage of reduction in hue components of natural images. Among the different color space compared, the proposed method achieves better compression and is well suited for small and large size natural images. Proposed method make use of a double level RCT on the existing BBWCA algorithm and resulted in improving the compression ratio by 46 percentage.

Keywords: BWCA,Double level RCT,Lossless Compression,Y Component

1. Introduction

Presentation of images without losing information while compression remain as a great challenge for research community. Lossless image compression algorithm allows the original image data to be perfectly reconstructed from the compressed data. Lossless image compression is used in cases where it is important that the original and the decompressed images must be identical, like medical industry, satellite imagery, remote sensing etc. Raster map compression and information hiding domains make use of lossless compression techniques6,7. Color images, especially high resolution images, like medical images or satellite images prefer lossless compression algorithms1−4. As these compression techniques mainly dependent upon redundancy between image pixels18, it is very difficult to preserve its quality while reducing the image data. In most of the cases images are transformed into various domains to increase

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the redundancy.

Conversion of images into different color spaces provides more characteristics of that image. Various linear and nonlinear transformations\(^9\) of the RGB and tri-stimulus color spaces can be used to describe the color image via a transformed plane. Such transformations help to bring out perceptual redundancy that are present in the image pixels and can thus improve the compression rate. Digital images which are represented in device-dependent RGB color space can be easily transformed\(^9\) into various color space using the transformation formulas\(^9\).

RCT are totally reversible integer color transforms and are used in both lossless and lossy compression methods by JPEG2000\(^8\),\(^19\). HSV and YUV are such RCTs which helps to increase the redundancy in images and thus enhance compression. YUV transformation before encoding helps to reduce the entropy of the images and thus achieves higher compression\(^11\). A new lossless color image compression scheme is developed by using this property of YUV in Bi-level BWCA\(^1\) which is a variant of Burrows Wheeler Compression Algorithm (BWCA)\(^12\). Here row-wise and column-wise BWT is applied on YUV transformed image data which produce better compression than single level BWTs. HSV can be used in natural image compression where the hue components shows great reduction in the number of unique symbols\(^5\). In the proposed work, the above mentioned two compression techniques for color images are combined to achieve better compression of natural color images through a double level RCT scheme in BBWCA. Double level RCT gives much better compression rate than any other single level RCTs in case of natural color images.

The following sections describes the proposed double level RCT-based BBWCA. Analysis of the different stages and their effects on image data are presented in section 3. The experimental results for test images are given in section 4 followed by concluding remarks in section 5.

2. Proposed Method

Most of the conventional compression methods fails to provide better compression rate without losing information. Even though many works have been reported in the literature, those can be still enhanced to obtain less number of unique symbols to achieve better compression ratio. Utilizing the double level reversible color transformation, we have experimentally proved that around 46 percentage of improvement can be made in the compression ratio compared to the existing methods.

Our proposed method utilizes the characteristics of double level RCT in BBWCA methodology which is introduced by Aftab khan et al.\(^1\). We have experimentally proved that, applying double level RCT on images provide better compression than any single color transformation. The proposed method is designed for compressing natural color images, where the number of unique hue component symbols can be substantially reduced. Since the hue component shows great redundancy, we use HSV as the first level RCT. YUV is used as the second level RCT which shows tremendous reduction in the number of unique symbols in the Y component. The output of double level RCT is given as the input to bi-level BWCA\(^1\) which helps to yield high compression rate. Figure 1 shows the schematics of the data flow and processing steps in the proposed lossless image compression using double level RCT in BBWCA.

2.1. First Level RCT

For natural images if we take hue components, it has limited number of unique values. The proposed method is designed for natural images exploiting this scenario. So the first level RCT comprises of converting the source image or the original image into HSV color space. Fig 2: shows the original image of Kodim22.png which is taken from natural image dataset Kodak16 and it's transformed HSV Image.

H and S components are converted into unsigned integer format since they are in normalized form in HSV color model. After conversion, each component of HSV (hue, saturation and value) are in the range of 0-255. The DC Level shifting\(^20\) operation is performed in each component to make it in the range of -128 to +127. For that we deduct 2\(^n\) from those pixels whose values are greater than +127. Since we are dealing with digital images, each gray level pixel
value takes only 8 bits of data with values ranging from 0 to 255. Therefore we have fixed the value of $n$ as 8 in our proposed method.

H, S, V contain negative values at this stage. So those negative values can be represented using 2’s complement. The DC level shifting and 2’s complement operation can be mathematically written as:

$H_2, S_2, V_2 \xrightarrow{2’s \text{ complement}} H, S, V - 2^n \vee H, S, V \geq \frac{2^n}{2}$  \hspace{1cm} (1)

where $H_2, S_2, V_2$ are the 2’s complement representation of $H, S$ and $V$, respectively.

2.2. Second Level RCT

The output of first level RCT shows great redundancy in hue components, which is given as the input to second level RCT where YUV transformation is used. YUV transformation before encoding helps in reduction of entropy which can be used for better compression. HSV to YUV color transformation can be mathematically represented as follows:

Forward Transform:

$Y = \left[ \frac{H_2 + 2S_2 + V_2}{4} \right]$

$U = H_2 - S_2$

$V' = V_2 - S_2$  \hspace{1cm} (2)
Similarly, the reverse color transform for the above equation (2) can be given as:

Reverse Transformation:

\[
\begin{align*}
S_2 &= Y - \left[ \frac{U + V'}{4} \right] \\
H_2 &= U + S_2 \\
V_2 &= V' + S_2
\end{align*}
\]  

(3)

Figure 3 shows a comparison of unique symbols in Y component when applying normal YUV transformation and double level RCT. To explain the effect of double level RCT a sample patch is taken from the image Kodim22.png, and from the patch matrix A and matrix B is formed by applying normal YUV and double level RCT, respectively. Matrix A shows the elements of Y component after applying normal YUV transformation. Matrix B denotes Y components after applying double level RCT according to our proposed method. It is evident from the figure that, 27 unique components obtained on applying normal YUV in the patch (shown in matrix A) has been reduced to 20 components on applying double level RCT to the patch (shown in matrix B).

We have noted a huge difference in reduction of unique Y components in the combined HSV+YUV images compared to the normal YUV images. Figure 4 shows the effect of double level RCT for various images in Kodak image dataset16.

Another important fact is that after the double level RCT there is a slight increase in the number of unique components in U and V channels. Compression is enhanced as this increase in number of unique components of U and V are negligible compared to the reduction in number of unique components in Y. Thus we get a higher compression ratio in double level RCT conversion [HSV+YUV] as compared to single RCT [HSV or YUV]. Figure 5 shows the effect in the number of unique symbols in Y, U and V components of Kodim22.png taken from Kodak image dataset16 with and without HSV conversions.

2.3. BBWCA

The result of double level RCT shows great reduction in number of unique Y components and is given as the input to Bi-level BWCA\(^1\) introduced by Aftab khan et al.\(^1\) where row-wise and column-wise BWT is applied for better compression. In each level of BWCA, data is transformed and passed over to the next level. It starts with the BWT stage in the leftmost, then to the the global sort transform (GST) stage where data traverse through the move-to-front (MTF) transform and then through run-length encoding (RLE) to the last stage of the entropy coder (EC).
2.4. BWT

Core of BWCA is the BWT\textsuperscript{12}. RCT sorts permutations of the input data and groups together the repeated elements. RLE and MTF transform can be applied to the output data obtained at this stage as it contain the same elements of the data repeated multiple times\textsuperscript{15}. YUV image obtained after the second level RCT is the input to BBWCA algorithm. First, image will be undergoing BWT in its row-wise and in the next stage BWT will be applied in column-wise direction. Hence it has the name Bi-level BWT. Bi-level BWT promises better compression than single level BWT. Experimental results are shown in Table 1.

Table 1. Single BWT Vs Bi-Level BWT.

| Color Space          | RGB     | YUV     |
|----------------------|---------|---------|
|                      | Single BWT | Bi-Level BWT | Single BWT | Bi-Level BWT |
| Original Image Size  | 589824   | 589824  | 589824   | 589824     |
| Compressed Image Size| 515398   | 488803  | 473332  | 444458     |
| Compression Ratio    | 1.1444  | 1.2067  | 1.2461  | 1.3271     |
The Burrows Wheeler Transform for a substring $w$ of a string $s$, $\text{bwt}(s)$, can be expressed as

$$\text{bwt}(s) = \bigcup_{w \in A^k} \pi_w(ws)$$

(4)

where $A = a_1, \ldots, a_n$ is an alphabet and $w$ is a word of length $k$. Permutation of the string $w_s$ is given by $\pi_w(w_s)$. Zeroth-order entropy does not change as a result of permuting a string and for each substring $w$ of $s$, elements following $w$ in $s$ are clustered together inside $\text{bwt}(s)$. That is the reason why BWT is essential for compression.

Applying BWT, row-wise and column-wise, causes better correlation of data and results in better compression as it creates a better homogeneity of gray values. The output from the bi-level BWT stage are passed to MTF Encoder after ordering the data in zigzag manner. It can help in grouping together of repeated values.

2.5. MTF

Second stage of BBWCA comprises of transforming the symbols to a global context from the local context. Here we make use of MTF transformation for this purpose. It is a list update algorithm (LUA), which replaces the input symbols with their index from a list. The list for an 8-bit image contains pixel intensities in the range 0 - 255. Symbol in the list is moved to the front once the symbol is replaced with the index from the list. Thus smaller index values will be given for frequently occurring symbols in the data.

The output from the bi-level BWT stage are passed to MTF encoder after ordering the data in zigzag manner. It can help in grouping together of repeated values. Move-To-Front encoder replaces a symbol by the number of distinct symbols that occurred since its previous run. This output is further compressed using a run length encoder.

2.6. RLE

In order to reduce element runs in the MTF encoder output, third stage of the proposed double level RCT based BBWCA uses the run-length encoding (RLE). Various algorithms are proposed for this purpose. Abel introduced RLE-BIT and RLE-EXP algorithms, and Burrows and Wheeler used the zero run transform (RLE-0). The proposed model make use of the RLE-0 scheme.

2.7. Entropy Encoder

The last stage of the proposed double level RCT based BBWCA is the entropy coding, which compresses image data into less storage space by replacing frequently occurring symbols by fewer bits. Proposed scheme uses Huffman transformation as time complexity is less compared to arithmetic coding.

2.8. Decoding

The decoding of lossless compression reconstruct the exact original data from the compressed data. In the proposed method the original image can be decoded by applying operations which is used in the encoding procedure in reverse manner.

The detailed encoding and decoding procedures of the proposed method are shown in Algorithm 1.

3. Results and Analysis

Our proposed method was implemented in MATLAB 2015. Experiments were done using — natural image dataset Kodak. Experimental results are given in Table 2. It is evident from table that the proposed method offers better compression compared to the technique used in single RCT. Consider the example of Kodim9.png taken from the Kodak image dataset. Compression ratio shows a significant improvement from 1.5386 to 2.2316 compared to the BBWCA. Double level RCT exploiting compression mode in HSV and YUV color space offers higher compression.
A new lossless color image compression scheme is developed by using the property of reversible color transforms. HSV and YUV are reversible color transforms which help to increase the redundancy in images thereby enhancing compression. YUV transformation before encoding helps to reduce the entropy of the images and thus achieves higher compression.  

Table 2. Compression Ratio Comparison.

| Image  | RGB   | HSV   | YUV(BBWCA) | Proposed |
|--------|-------|-------|------------|----------|
| Kodim02 | 1.4111 | 1.6155 | 1.563      | 2.2604   |
| Kodim04 | 1.1765 | 1.2589 | 1.3518     | 2.1249   |
| Kodim06 | 1.2004 | 1.3580 | 1.4591     | 2.1181   |
| Kodim08 | 1.558  | 1.1208 | 1.2745     | 1.8178   |
| Kodim09 | 1.2528 | 1.3209 | 1.5386     | 2.2316   |
| Kodim10 | 1.209  | 1.2404 | 1.458      | 2.1246   |
| Kodim13 | 1.1371 | 1.2525 | 1.3735     | 1.9709   |
| Kodim16 | 1.215  | 1.3267 | 1.5784     | 2.1904   |
| Kodim17 | 1.1818 | 1.2047 | 1.5107     | 2.07     |
| Kodim21 | 1.2296 | 1.2871 | 1.4106     | 2.1989   |
| Kodim22 | 1.1991 | 1.2305 | 1.3194     | 2.1191   |
| Kodim24 | 1.1592 | 1.2292 | 1.3821     | 2.00     |
| Average | 1.2024 | 1.2871 | 1.435      | 2.103    |

compared with rest of the methods. Average compression ratio has shown improvement of 46 percent after using the double level RCT.

Graphical representation of the results presented in Table 2 which are obtained using our proposed method in the images from Kodak Image dataset are shown in Figure 6. It is very evident from the chart that our proposed method shows a significant improvement in the compression ratio compared to different single level RCTs.

4. Conclusion

Lossless images compression remain as a great challenge for the research community even today. Medical industry, satellite imagery, remote sensing etc. make use of lossless compression schemes where the loss of information is very critical. HSV and YUV are reversible color transform which helps to increase the redundancy in images thereby enhance compression. YUV transformation before encoding helps to reduce the entropy of the images and thus achieves higher compression. A new lossless color image compression scheme is developed by using the property

Algorithm 1 Double Level RCT Compression Algorithm

1: procedure Encoding
2: Input: An Original Source Image I
3: Output: Compressed Image Data D
4: \(H, S, V \rightarrow \text{RGB to HSV}(I)\)
5: for \(i = 0\) to Sizeof\((H, S, V)\) do
6: \(\text{if } (H_i, S_i, V_i) > 127\) then
7: \((H_i, S_i, V_i) \leftarrow 256 - (H_i, S_i, V_i)\)
8: end if
9: end for
10: \(H, S, V \rightarrow \text{Decimal to } 2^t\text{'s Complement}(H, S, V)\)
11: \(Y, U, V' \leftarrow \text{HSV to YUV}(H, S, V)\)
12: \(d_1 \leftarrow \text{Row wise BWT Encoding}(Y, U, V')\)
13: \(d_2 \leftarrow \text{Column wise BWT Encoding}(d_1)\)
14: Order \(d_2\) in Zigzag Manner
15: \(d_3 \leftarrow \text{MTF Encoding}(d_2)\)
16: \(d_4 \leftarrow \text{RunLength Encoding}(d_3)\)
17: \(D \leftarrow \text{Huffman Encoding}(d_4)\)
18: end

1: procedure Decoding
2: Input: Compressed Image Data D
3: Output: Decoded Source Image Data I
4: \(dA \leftarrow \text{Huffman Decoding}(D)\)
5: \(d_3 \leftarrow \text{RunLength Decoding}(d_1)\)
6: \(d_2 \leftarrow \text{MTF Decoding}(d_3)\)
7: \(\text{InverseZigzag : Arrange } d_2\) in 2D Matrix format
8: \(d_1 \leftarrow \text{Column wise BWT Decoding}(d_2)\)
9: \(Y, U, V' \leftarrow \text{Row wise BWT Decoding}(d_1)\)
10: \(H, S, V \leftarrow \text{YUV to HSV}(Y, U, V')\)
11: \(H, S, V \leftarrow 2^t\text{'s Complement to Decimal}(H, S, V)\)
12: for \(i = 0\) to Sizeof\((H, S, V)\) do
13: \(\text{if } (H_i, S_i, V_i) < 0\) then
14: \((H_i, S_i, V_i) \leftarrow 256 + (H_i, S_i, V_i)\)
15: end if
16: end for
17: \(I \leftarrow \text{HSV to RGB}(H, S, V)\)
18: end
of YUV in Bi-level BWCA which is a variant of Burrows Wheeler Compression Algorithm (BWCA). The double level RCT based bi-level BWCA provide better compression ratio for natural images than any other single RCT based methods. The experimental results shows that in the first level RCT there is a large reduction in the number of unique symbols in the hue components of natural images, thus produce large reduction in the number of unique Y components in the second level RCT. The proposed algorithm provide better results for small and large sized natural color images and showed 46 percentage improvement compared to previously developed BBWCA scheme. Performance of this algorithm can be further improved by exploiting various color space combinations.

References

1. Aftab Khan, Ashfaq Khan. Lossless color image compression using RCT for bi-level BWCA. Springer-Verlag ;2014.
2. Ouni, T., Lassoued, A., Abid, M. Lossless image compression using gradient based space filling curves (G-SFC). Signal Image Video Process. 9(2), 2015 ; p.277-293
3. Anusuya, V., Raghavan, V.S., Kavitha, G. Lossless compression on MRI images using SWT. J. Digit. Imaging 27(5), 2014; p.594–600
4. Srinivasan, K., Daewels, J., Reddy, M.R.A two-dimensional approach for lossless EEG compression. Biomed. Signal Process. Control 6(4), 2011; p.387-394
5. http://dsp.stackexchange.com/questions/2687/why-do-we-use-the-hsv-colour-space-so-often-in-vision-and-image-processing
6. Mao, Q. Efficient and lossless compression of raster maps. Signal Image Video Process. 9(1), 2015; p.133-145
7. Sun, W., et al. High performance reversible data hiding for block truncation coding compressed images. Signal Image Video Process. 7(2), 2013; p.297-306
8. Skodras, A., Christopoulos, C., Ebrahimi, T. The Jpeg 2000 still image compression standard. IEEE Signal Process. Mag., 2001; p.36-58
9. Colantoni, P., A. Color space transformations, 2004.
10. de Queiroz, R.L. On independent color space transformations for the compression of CMYK images. IEEE Trans. Image Process 8, 1999; p.1446–1451
11. Chou, C.H., Liu, K.C. Colour image compression based on the measure of just noticeable colour difference. IET Image Process. 2(6); 2008, p.304-322
12. Burrows, M., Wheeler, D.J. A block-sorting lossless data compression algorithm. SRC Research Report 124. Digital Systems Research Center, Palo Alto; 1994.
13. Balkenhol, B., Shtrakov, Y.M. One attempt of a compression algorithm using the BWT; 1999.
14. Eko Darwiyanto, Heru Anugrah Pratama, Gia Septiana. Text Data Compression for Mobile Phone Using Burrows-Wheeler Transform, Move-To-Front Code and Arithmetic Coding. International Conference on Information and Communication Technology; 2015.
15. Abel, J. Improvements to the BurrowsWheeler compression algorithm: After BWT stages. ACM Trans. Comput. Syst.; 2003.
16. Kodak Image dataset http://r0k.us/graphics/kodak/
17. Manzini, G. An analysis of the BurrowsWheeler transform JACM 48. 3rd ed. ; 2001. p.407-430
18. Gonzalez, R.C., Woods, R.E. Digital Image Processing, Prentice-Hall Inc, 3rd ed. New Jersey; 2002.
19. Rabbani, M., Joshi, R. An overview of the jpeg 2000 still image compression standard. Signal Process. Image Commun. 17(1); 2002. p.3-48