Prediction Truncation Algorithm Based on Regression Analysis for Embedded Block Coding

Yanjun Liu and Zupeng Liu

***Abstract*—In order to solve the problems of execution complexity and time waste in compression process induced by Post Compression Rate Distortion(PCRD) Optimization in embedded block coding in JPEG2000, this paper proposes an effective method to promote coding efficiency-embedded block coding algorithm with prediction truncation based on regression analysis. This algorithm predicts the truncation points based on regression formula derived from linear regression analysis. It avoids scanning and encoding the bit planes that can be truncated, discards the time-consuming rate-distortion truncation processing, so that the algorithm is able to speed up the compression process. The experiment results show the algorithm obtains obvious promotion efficiency of coding speed.**

***Index Terms*—JPEG2000, embedded block coding, regression analysis, prediction truncation**

I. Introduction

This paper adopts the static image compression standard JPEG2000 based on discrete wavelet transform [1], in 1998, David Taubman brought forward the optimized truncation of embedded block coding [2] (Embedded Block Coding with Optimal Truncation, EBCOT) as the core algorithm, which has flexible organization forms of code stream, robust fault tolerance, excellent low bit-rate compression performance, a variety of progressive transmission mode.

The embedded block coding algorithm for optimization truncation is mainly divided into two parts: Tier-1 encoding, which is the most important embedded coding to complete the EBCOT, the main task is doing the plane sweep of fractional bits to independent code block, provides coding symbols and their context information, proceeds binary arithmetic coding; Tier-2 coding, adopting Post Compression Rate Distortion(PCRD) Optimization, rate control optimize truncation is proceeded to the bit stream of Tier-1 encoding, Tier-2 code organizes and forms the output stream with quality layer, where each code block is different to the contribution of image quality.

Embedded block coding algorithm of JPEG2000 in Tier-1 coding stage, generates the bit stream to all the independent code block coding, namely uses the three scanning channels to scan each bit plane in turn, and also calls the corresponding coding primitives to encode the bits of each coefficient; in the Tier-2 coding phase according to the target bit rate to truncate and generate abstract quality layers, especially for the case of high compression ratio such as 0.125 or 0.0625, the majority of the coefficients which have been encoded in tier-2 stage are discarded through truncation. Obviously, a lot of running time is wasted in the coding of coefficient bits that will be truncated. This paper proposes the predict truncation algorithm based on regression analysis, while embedded coding it can predict plane scan code stream position of the truncated points, give up coding to the coefficients bits that will be discarded, and give up the rate distortion calculation and optimization truncation based on cycle search in Tier-2 coding, thus greatly improves the encoding speed.

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II. Prediction Truncation Algorithm

Suppose independent code block B_i is being encoded, after Tier-2 optimization and truncation the length of bit stream is $L_i^{'}$, the length of target bit stream is L_i^f, and the bit stream length generated by each separate code block occupying the ratio of target code stream length is $R_i = L_i^{'}/L_i^f$. And in the channel scanning process, each code block B_i generating the bit stream length is $L_i^{p^k}$ by scanning the channel, the sum of the bit stream length is:

$$currentsize = \sum_k L_i^{p^k} \tag{1}$$

If the value R_i can be predicted in advance, the following algorithm can be used to predict the truncation.

For each B_i

Initialize currentsize=0

Initialize Targetsize= $R_i \times L_i^f$

For each bit-plane(b7,b6,...,b0)

For each coding pass(P_1^p, P_2^p, P_3^p *)*

Generate block bitstream

$\text{Currentsize}+ = L_i^{p^k}$

If (currentsize>Targetsize)

Goto next B_i

End For

End for

End For

III. Regression Analyses

The prediction truncation algorithm mainly depends on the

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Predict value of R_i . Through a series of observations regression analysis method can find the regression equation between response variable R_i and independent variable as empirical formula of predicting R_i.

A. RESPONSE Variables and Independent Variables

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables. Observations $\hat{R}_i$ of the response variable R_i can be obtained by the original encoding algorithm; the truncation length value $\hat{L}_i^{'}$ of each separate code block B_i can be obtained by the following formula:

$$\hat{R}_i = \frac{\hat{L}_i^{'}}{\sum_i \hat{L}_i^{'}} \quad (2)$$

Independent variable mainly has the following items: (1) the sub-band weight value W_i corresponding to B_i : the sub-band weight value is mainly used to calculate the MSE value of each coefficient after quantization coding; it is used to measure the importance of different sub-band coefficients. In general, sub-band energy is more concentrated, the value W_i is greater. To 5/3 wavelet transform, the image size is 128 × 128, the resolution rating of wavelet transform is 4, the weights of each sub-band distribution are illustrated in Figure 1. Obviously, the size of weights decreases with the increase of the resolution series.

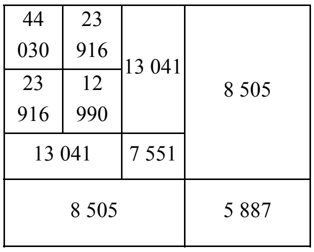

Fig. 1. The distribution sample of sub-band weights.

In order to facilitate observation, in accordance with the formula (3) the right value W_i is converted to ratio $W_i^{'}$.

$$W_i^{'} = \frac{W_i}{\sum_i W_i} \quad (3)$$

Thus $W_i^{'} \in (0,1)$, after observing a set of $W_i^{'}$ and observations $\hat{R}_i$, Fig. 2 is drawn below.

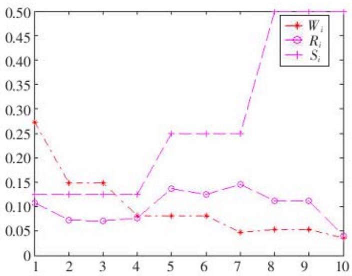

Fig. 2. The relationship curve image between weights and truncated length of code block.

$W_i^{'}$ is the transformed weight, R_i is the ratio of bit-stream truncation length of independent code block B_i, S_i is block size, for convenient observation, block size 16, 32 and 64 have respectively divided by image size 128. The abscissa is the number of code block; the order is illustrated in Figure 3.

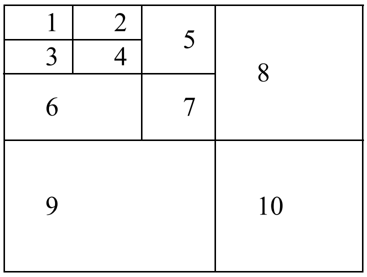

Fig. 3. The number order of separate code block

From Fig. 2, these can be seen that: (1) in the condition of same block size, the value R_i decreases with the reduction of W_i; (2) the several code block 4,7, and 10 belong to HH high frequency sub-band, which are not entirely comply with this rule. Based on these two observations, the two independent variables S_i and K_i are added. The size of code block B_i is S_i, the actual use value is $S_i^t = S_i / size$, size is the image size. Block size 16, 32 and 64 are converted into 0.125, 0.25, and 0.5. The tag of sub-band component of code block B_i is marked as 1, LL sub-band tag is 1, LH and HL sub-bands are marked as 2, the tag of HH sub-band is marked as 3. The values of K_i are illustrated in Table I.

TABLE I : THE VALUE OF SUB-BAND MARK.

Code Block i	k_i
1	1
2,3,5,6,8,9	2
4,7,10	3

The proportion of channel scanning frequency of code block B_i is T_i . The number of scanning channel P_i is as follows:

$$P_i = 3 \times b_i^{\max} - 2 \quad (4)$$

In the expression, $b_i^{\max}$ is the highest bit plane of the code block B_i, the coefficient's initial state of independent code block B_i is non-significant, the highest bit plane significant expansion and amplitude refine scan can be skipped, and so two scan numbers need to reduce. The observed value $\hat{T}_i$ of the independent variable can be calculated as:

$$\hat{T}_i = \frac{\hat{P}_i}{\sum_i \hat{P}_i} \quad (5)$$

After all the independent variables and response variables are defined, the linear regression equation can be established.

$$R_i = \beta_0 + \beta_1 W_i^t + \beta_2 T_i + \beta_3 S_i^t + \beta_4 K_i \quad (6)$$

B. The Solving and Analysis of Regression Equation

In order to solve the linear regression equation, a lot of response variables and independent variables are needed. By the regression analysis tool [3], 300 groups of observation values are analyzed by multiple linear regression analysis, parameter estimate values are obtained:

$\beta_0 = 0.29929 \quad \beta_1 = -0.22024 \quad \beta_2 = 1.2621$

$\beta_3 = -0.10928 \quad \beta_4 = -0.10739$

Parameter estimate value putting into equation (6) can obtain the linear regression analysis equation. Variance analysis results of regression analysis are shown in Table II. S_R is the deviation sum of squares, S_e is the residential sum of squares, and S_T is the regression sum of squares.

TABLE II: RESULTS OF VARIANCE ANALYSIS

Variance source	Deviation square	Degree of freedom	Variance
Regression	[S_R=0.386 6]	[m-1=4]	[V_R=0.096 65]
Error	[S_e=0.315 3]	[n-m=295]	[V_e=0.001 068 8]
Sum	[S_T=0.702 0]	[n-1=299]	[ ]
Related coefficient 0.742 16			
Residual standard deviation 0.032 694			

After obtaining parameter estimation value, the linear relationship of regression equation needs to determine if it is significant. Firstly according to the analysis of variance table to calculate the linear correlation coefficient R, it is illustrated in expression (7):

$$R = \sqrt{\frac{S_R}{S_T}} \tag{7}$$

The correlation coefficient is closer to 1, indicating that the linear relationship is more significant. Calculating according to the results of variance analysis table, the linear correlation coefficient R is 0.74216, indicating that the independent variable is a linear relationship with response variable. Residual standard deviation S represents the precision of linear regression equation; the accuracy of the above regression equation can be obtained 0.032694 according to the formula (8).

$$S = \sqrt{\frac{S_e}{n-m}} \tag{8}$$

In addition to using the linear correlation coefficient, hypothesis testing can also be used to do significance test. Assuming H_0 is non-linear relationship, H_1 is linear relationship.

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$$
$$H_1 : \exists \beta_i, i = 1,2,3,4 \ \ \beta_i \neq 0$$

According to the formula (9), F value is 90.4285.

$$F = \frac{V_R}{V_e} = \frac{S_R/(m-1)}{S_e/(n-m)} \tag{9}$$

Under the conditions of significant level α = 0.01, $F_{0.01}(4,295) = 3.3833$, because $F > F_{0.01}(4,295)$, H_0 is refused, that means the linear relationship is significant. Until now, the relationship between independent variables and response variables is considered as linear.

Besides proceeding linear significant analysis, each coefficient should do the significance test to determine the impact extent of the independent variables on the response variable. Each coefficient $\beta_j(j = 1,2,3,4)$ is used to do hypothesis test: If $|t_0| < t_{\alpha/2}(n-m)$ is accepted then receive H_0; if $|t_0| \geq t_{\alpha/2}(n-m)$ then refuse. The coefficient significance conclusion results in regression analysis tool [3] are: β_1 is not significant, β_2 is significant, β_3 is not significant, β_4 is not significant. In these parameters, only the impact of β_2 is significant to the response variable, which means β_2 has the largest impact on the predictive value. This is because β_2 is the coefficient of frequency proportion T_i of the channel scanning, what T_i reflected is the characteristics of different images, and other parameters have relationship with sub-band and block size.

Although the parameters β_1, β_2 and β_3 are not significant, but this does not mean these parameters can be removed from the regression equation. If rewriting the linear equation (6) into a new linear equation:

$$R_i = \beta_0 + \beta_2 T_i \tag{10}$$

The regression analysis of variance table is obtained in Table III.

TABLE III: THE ANALYSIS OF VARIANCE OF SIMPLIFYING THE REGRESSION EQUATION

Variance source	Deviation square	Degree of freedom	Variation
Regression	[1.0063E-004]	[1]	[1.0063E-004]
Error	[0.7019]	[298]	[0.0024]
Sum	[0.7020]	[299]	[ ]
Related coefficient 0.011973			
Residual standard deviation 0.048531			

From the table, the correlation coefficient R is only 0.01, which is far less than 1. And there is no linear correlation between independent variables and response variables. No matter remove anyone of a significant parameter β_1, β_3 or β_4, through variance analysis table, the correlation coefficient and residual standard deviation (Table 4) are not as good as the results in Table III.

TABLE IV: VARIANCE ANALYSIS AFTER DELETING INSIGNIFICANT PARAMETERS

	Delete β_1	Delete β_3	Delete β_4
Related coefficient	0.507 44	0.713 78	0.200 76
Residual standard deviation	0.041 963	0.034 107	0.047 707

IV. EXPERIMENTAL DATA

The linear regression equation is embedded in the prediction truncation algorithm, and through the test image compression, compares the mentioned encoding speed and the reconstructed image quality of PSNR values between this algorithm and the original algorithm, which are shown in Table V and Table VI, the compression ratio is 0.125, the wavelet transform layer is 4. As in the multi-tasking operating system, using the timing method evaluation algorithm speed is very difficult, the multi-task switching and machine load will greatly affect the determination of time. Therefore, in this paper, this method is used to measure the computational complexity with calculating the number of basic operations. Select the number of calls of bit coding function jpc_mqenc_putbit in Geojasper [4] as the basic unit of measuring computational complexity, and this function always appears in pairs with the operations of updating context, therefore it can very accurately measure the efficiency of algorithm.

TABLE V : THE COMPARISONS OF THE CALL NUMBERS (SPEED) BETWEEN TWO ALGORITHMS (TIMES)

	Lena	Boat	Couple	Aerial	Goldhill	Baboon
Original algorithm T1	963 95	100 189	100 984	115 947	99 441	107 937
Prediction algorith m T2	4 984	4 924	4 818	5 889	5 234	4 609
T2/T1	0.051 704	0.049 147	0.047 711	0.050 790	0.052 634	0.042 701

TABLE VI: THE COMPARISONS OF IMAGE QUALITY (PSNR) BETWEEN TWO ALGORITHMS (DB)

	Lena	Boat	Couple	Aerial	Goldhill	Baboon
Original algorithm P1	32.824 146	31.151 045	31.653 737	25.354 011	31.430 386	28.369 106
Prediction truncation P2	32.611 815	30.568 089	31.433 413	24.798 547	30.839 875	27.540 490
$\Delta PSNR$	-0.212 331	-0.582 956	-0.220 324	-0.555 464	-0.590 511	-0.828 616

From the experimental results, in T1 encoding stage, the number of prediction truncation algorithm of calling basic coding operations is generally only 4% to 5% of the original algorithm, and the predict truncation algorithm abandons the rate distortion search to the optimal hierarchical truncation point in T2 encoding stage, while the latter generally occupies about 35% of the JPEG2000 encoding time. Comparing prediction truncation algorithm PSNR value with the original algorithm, the difference range is between 0.2 ~ 0.8dB. From Figure 4, even in high compression ratio, the naked eyes are difficult to distinguish the difference between predict truncation algorithm and the original algorithm about the differences in subjective quality of reconstructed image. Small PSNR loss can exchange significant speed gains, which proves prediction truncation algorithm is indeed effective.

Fig. 4. The image quality compare between prediction truncation algorithm and the original algorithm (Goldhill, compression rate is 0.0625).

V. CONCLUSIONS

This paper proposes the embedded block coding prediction truncation algorithm based on regression analysis, according to regression equation based on multiple linear regression analysis to predict the cut-off point of the JPEG2000 bit-plane scanning, the channel after the prediction cut-off point and the bit-planes do not have to continue coding, and discard the complex and time-wasted rate distortion search in T2 coding for the best layered cut-off point, thereby which significantly improves the coding efficiency, meanwhile ensures that the subjective reconstruction quality of image is not significantly reduced.

Though the error of empirical formula can not be ignored, estimation of exceeding the scope of the sample observations can not be evaluated. But experimental results show the accuracy of the empirical formula on image quality is not so important than expected. This is mainly because the coefficient energy after wavelet transform concentrates in the sub-bands, if the truncation length of these code blocks prediction is greater than the actual length, more low-frequency coefficients are coded, the relevant coding number of coefficients in high-frequency sub-band will be reduced. And the coding sequence of code block is from the low-frequency sub-band to high-frequency sub-band, so this error has little effect on image quality.

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