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Application of Residual Analysis in the Video Coding Fast Algorithms

Na Sun*1, Qian Qiao2

School of Information Engineering, Communication University of China, P.R. China

No.1 Dingfuzhuang East Street, Chaoyang District, Beijing, 100024, P.R. China

*1shelia323@sohu.com; 2qiaoqian628@gmail.com

Abstract

High coding efficiency is the ultimate goal of developing video coding technology, but it is usually achieved at the cost of increased computation complexity. Thus, how to reduce as much computation complexity as possible while ensuring high coding efficiency becomes an important subject in the study of video coding technology. This paper has introduced several typical fast algorithms which are based on residual coefficients.

Keywords

Residual; Video Coding; Fast Algorithm

Introduction

The main process of H.264 video encoding is that the best mode is determined through comparison among several prediction modes, and the consequent residuals go through 4×4 integer discrete cosine transform (DCT) to eliminate their spatial correlation; after that a quantization parameter is determined according to the size of the image dynamic range, and the DCT coefficients go through a quantization process ruled by the quantization parameter, then the coefficients after quantization will go through the run length encoding and entropy encoding process and be exported as bit stream. As residual coding makes up the kernel of code stream, the ability of its relevant algorithms has tremendous influence on the performance of both encoder and decoder. This paper comprehensively demonstrates fast algorithms which are based on residual coefficients, taking H.264 as example. The focus of further research is also put forward.

Overview of Residual-based Fast Algorithms

Motion estimation, mode decision, transformation and quantization are very important in the video compression coding. Also they are always the focal point in the video coding algorithm optimization. Studies of residual-based fast algorithms are carried out from these angles without exception.

Motion Estimation Optimization Using Residual Characteristics

Lu's work is a typical example using features of residual data to optimize motion estimation algorithm. It has been pointed out that if the motion vectors of adjacent blocks are close to each other, their residuals are usually close too. Thus, one can determine whether to stop motion search or not by comparing the neighboring macroblocks' residuals. Moreover, search patterns used can also be chosen according to the correlation between residual blocks--when the correlation between residuals is low, complex search pattern is utilized; otherwise, simpler pattern is adopted.

Residual Distribution Based Mode Prediction

Currently, many scholars have conducted in-depth studies into the mode prediction section of video coding, in order to achieve algorithm optimization. Wang first got the residuals of each 4×4 subblock after motion compensation by performing macroblock-level motion search pretreatment, then determined if the current inter-frame block should be further divided according to the size and distribution (uniform or not) of the residuals. The algorithm reduced the computation complexity, but the pretreatment of motion search has caused growth in bit rate at the same time.

Prediction of Zero-value Residual

It is a good strategy for H.264 algorithm optimization that researchers predict the 0-value residuals after DCT and quantization to reduce some of the computation expense. And there are many research findings now.

In Sheng's work quantized DCT coefficients of the residual block and the coded block have been compared, then the non-zero quantized DCT coefficients were divided into two categories and then coded respectively. In addition to the residual block, this method also requires the quantization and coding of the coded block, thus a great amount of calculation arose.

In Jing's work a threshold TH (u, v) has been set, then the all-zero blocks were predicted by comparing the MSE (Mean Squared Error) in the motion search with TH (0, 0). Afterwards, the MSE of non-zero block was compared with TH (u, v) to predict non-zero block's 0-value DCT coefficients, thus the overhead of DCT and quantization dropped.

Wang H proposed another 0-value prediction method. However, the Hadamard transform in H.264, which is attached to the integer DCT and quantization performed on the residual blocks failed to be taken into consideration. On the basis of Wang's literature, SATD (Sum of Absolute Transformed Difference)-based zero value prediction was added in Xiang's work, in order to fit for the Hadamard transform in intra 16×16 and chroma 4×4 prediction mode, thus the cost of DCT and quantization was further reduced.

Laplace and Gaussian models were utilized respectively in Pao and Wang's work to fit the distribution of different positions' residuals after motion compensation and prior to DCT transform. The corresponding variance was studied to predict the variance of each position's residual, and then the threshold was determined by synthesizing the residual variance and QP (Quantization Parameter), subsequently quantized zero values were predicted, reducing the number of pixels that need to be transformed and quantized, and the goal of reducing computation complexity has been achieved.

Research and Application of DCT Coefficient Distribution Model

Studying the residuals is a good starting point to improve the coding efficiency of H.264. There are a lot of operations performed on the residuals—DCT, quantization and entropy coding. If there are any rules in the residuals of a macroblock or a block, optimization of algorithms will be achieved more easily. The distribution of residual coefficients has been investigated for about 20 years. Results of the researches concerning residual distribution in these years are summarized below.

Distribution Model of the DCT Coefficients

By synthesizing the studies of a number of scholars, it can be seen that currently there are mainly four models used for video sequences' DCT coefficient distribution fitting: Laplace model, generalized Gaussian model, α model and Cauchy model. Müller used generalized Gaussian distribution to calculate the ν value of the DCT coefficients, corresponding to their different positions. In his report it was pointed out that "In the same image, the ν values of the DCT coefficients corresponding to different positions are close to each other." Eude et al. tried to use a finite Gauss mixed distribution to fit the DCT coefficient distribution. Smoot et al. studied DCT coefficient distribution of color images. By comparing the luminance and chrominance channels, he found that "the data of the chrominance channel showed the same distribution as that of the luminance channel. However, when Laplace model is used to fit the DCT coefficients, there are more DCT coefficients close to zero in the chrominance channel, and parameters of the distribution model are usually larger there."

After that, a variety of experiments have been done to analyze and compare the various kinds of models, and different viewpoints and conclusions have been made about the most suitable model. Chen believes that Cauchy distribution is the optimal distribution model for AC coefficients after hypothesis testing of generalized Gaussian distribution and Cauchy distribution. Using KS (Kolmogorov-Smirnov) and $\chi 2$ algorithms, Zhu has drawn the conclusion that in most cases Cauchy distribution is the best fitting distribution model for DCT coefficients according to the Maximum Likelihood Estimation. In Bhuiyan's literature, the probability density function of the various models has been analysed and it was believed that inverse Gaussian distribution fits for DCT coefficients most.

Based on the models that have been proposed to fit DCT coefficients, there were also many scholars who synthetically analyzed the main four distribution models and a new model named Model MSW, which was proposed by Ma et al. It was believed that generalized Gaussian distribution model exhibits superior performance compared to other models in the mode decision section, while the other models perform better in rate control. It was also mentioned that different models fit for different types of frames and sequences. Consequently, if H.264 is expected to be optimized from different angles (via rate control, mode decision, etc.), different models should be adopted.

Generalized Gaussian distribution model and Laplace distribution model are more often adopted in H.264

algorithm optimization.

Application of DCT Coefficient Distribution Model

The distribution model of DCT coefficients is the starting point for a lot of residual-based researches, especially those who predict 0-value residual. Having a threshold is necessary for 0-value residual prediction, and usually the threshold is derived from analysis of residual distribution model's numerical characteristics. The results of DCT coefficient distribution researches are used in many relevant literatures to make predictions about 0-value quantized coefficients.

Conclusion and Perspective

At present, studies of residual coefficient based fast algorithms are mainly conducted in three directions: (1) to optimize the motion estimation process by using residual characteristics;(2) to predict the best mode by studying the distribution of DCT coefficients;(3) to reduce computation complexity of the DCT and quantization process by predicting the 0-value DCT coefficients. Desirable results in video compression optimization may be achieved if two or three of the above ways are synthesized. For example, in Wang Dayong's work directions (2) and (3) are combined, the first of which is responsible for the prediction of the best mode according to the numerical characteristics of different zones' residual distribution, and the second is for the prediction of the 0-value DCT coefficients to reduce computation complexity. Another example is that in Wang Zhengning's work the all-zero blocks predicted are taken as a prerequisite to give early stop to the motion estimation.

In addition, the theoretical foundation of 0-value residual prediction is that when the quantization parameter is large, the residuals after motion compensation in low rate 4×4 blocks are usually very small after the DCT and quantization process, and there will be a large number of all-zero coefficient blocks. Therefore, the focus of most of the existing literatures is on the prediction of the zero elements in all-zero or non-zero blocks. We suggest that the statistical laws of non-zero blocks should be taken into consideration in future residual-based fast algorithm researches.

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