An Improved Detection Method for Zero Quantized Blocks on H.264/AVC

Bo-Jhih Chen and Shen-Chuan Tai

Presenter: Bo-Jhih Chen
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Data Compression & Multimedia Comm. Lab. @EE.NCKU
Outline

- Introduction
- Preliminary
- Proposed Method
- Experimental Results
- Conclusions
Introduction

Motivation

- A 4-by-4 residual block (motion-compensated error)
- There are many zero quantized DCT coefficients after DCT/Q, especially in low bit-rate video coding.

Objective

- Early detect more zero-quantized coefficients before DCT/Q.
- Effective reduction of computational complexity.
An 4x4 integer transform in H.264

\[ F = AXA^T = W \otimes PF \]

**Quantization**

\[ |F_Q(u,v)| = |W(u,v)| \cdot MF(QP,u,v) + k >> qbits \]

**Note 1**

If \(|F_Q(u,v)| < 1\), then \(F(u,v)\) is considered as a zero quantized DCT coefficient.

**Def.**

ZQB (Zero Quantized Block): A DCT block consists of 16 zero quantized DCT coefficients.
The sufficient criteria for determining a zero quantized DCT coefficient.

For $W(u,v)$, 
\[
|W(u,v)| < \frac{2^{q_{\text{bits}}}-k}{MF(QP,u,v)}
\]

For $F(u,v)$, 
\[
|F(u,v)| < \frac{5}{6} Q_{\text{step}} \quad \text{where } Q_{\text{step}} = 0.625 \times 2^{QP/6}
\]
Introduction

For example:

Recall
\[ \mathbf{F} = \mathbf{AXA}^T = \mathbf{W} \otimes \mathbf{PF} \]

<table>
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<tr>
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<th>-3</th>
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<td>1</td>
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\[ \mathbf{AXA}^T \]
Floating

An input residual block \( \mathbf{X} \)

\[ \mathbf{F_{MAX}} \]
at Direct Current position

\[ \begin{array}{ccc}
-4 & 0.1 & 2 & 1.6 \\
-3 & -2.8 & 1.1 & 1.66 \\
3.5 & -1.3 & -2.5 & -0.5 \\
0 & 1.16 & 0.08 & -0.7 \\
\end{array} \]

\[ \mathbf{F} \]

\[ \begin{array}{cccc}
-16 & 0 & 8 & 10 \\
-21 & -30 & 7 & 15 \\
14 & -8 & -10 & -4 \\
-3 & 10 & 1 & -5 \\
\end{array} \]

\[ \mathbf{W} \otimes \mathbf{PF} \]
Energy conservation

\[ \sum_{x} \sum_{y} |f(x, y)|^2 = \sum_{u} \sum_{v} |F(u, v)|^2 \]

\[ f \xrightarrow{T} F \]

DC’s Energy

\[ E_{DC} = |F(0, 0)| = \left| \frac{1}{N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \right| \]

ACs’ Energy

\[ E_{ACS} = \sum_{u} \sum_{v} |F(u, v)|^2 - |F(0,0)|^2 = \left( N \sigma_f \right)^2 \]
The variance of the \((u,v)^{th}\) DCT coefficient

\[
\sigma_F^2(u,v) = \sigma_f^2[ARA^T]_{u,u}[ARA^T]_{v,v}
\]

- \(A\) is the DCT transform matrix.
- \(R\) is the covariance matrix.

By the central limit theorem,

\[
\gamma \sigma_F(u,v) < \frac{5}{6} \text{Qstep}
\]

**Note 2**

If \(\gamma = 3\),
the probability of \(F(u,v) = 0\) is about 99.73%.
Over 99% of DCT coefficients will be equal to zero, if

$$\sigma_f^2 < \frac{\left(\frac{5}{6} Q_{\text{step}}\right)^2}{\gamma^2 [ARA^T]_{u,u} [ARA^T]_{v,v}}$$

$\sigma_f^2$ denotes the variance of input residual data.
Proposed Method

For AC components,

\[
E_{ACs} = \sum_u \sum_v |F(u, v)|^2 - |F(0, 0)|^2 = N^2 \sigma^2_f
\]

\[
\sigma^2_f < \frac{\left( \frac{5}{6} Q_{step} \right)^2}{\gamma^2 [ARA^T]_{u,u} [ARA^T]_{v,v}}
\]

\[
E_{ACs} < \frac{N^2 \left( \frac{5}{6} Q_{step} \right)^2}{\gamma^2 [ARA^T]_{u,u} [ARA^T]_{v,v}} = TH_{ACs}(u, v)
\]
Proposed Method

- $TH_{ACS}$ is a symmetric matrix.
- $TH_{ACS}(u,v) = TH_{ACS}(v,u)$
- Wang et al. 2007
- Occurrence Probability (OP)

Based on the analysis, OP is over 80% on $3 \times 3$. Hence, the threshold of DC energy can be approximately $TH(0,2) = TH(2,0)$ instead of $TH(u,v)$. 

![Graph showing occurrence probability and DC energy threshold comparison]
**Proposed Method**

Our method for ZQB detection

\[
E_{DC} = |F(0, 0)| = \left| \frac{1}{N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \right| < \frac{5}{6} Q_{step}
\]

\[
E_{ACS} < TH_{ACS} (0, 2) = \frac{N^2 \left(\frac{5}{6} Q_{step}\right)^2}{\gamma^2 \left[A R A^T\right]_{0,0} \left[A R A^T\right]_{2,2}}
\]
Experimental Results

Performance evaluations

\[ \Delta P = P_{\text{Org.}} - P \]  
\[ \text{... PSNR Degradation} \]  
\[ \text{Positive : drop} \]  
\[ \text{Negative : gain} \]  

\[ DR(\%) = \frac{N}{N_z} \times 100\% \]  
\[ \text{... Detection Rate} \]  
\[ N: \# \text{ of the detected ZQBs} \]  
\[ N_z: \# \text{ of the actual ZQBs} \]  

\[ DQ(\%) = \frac{(N_z + N_n) - (N_m + N_f)}{N_z + N_n} \times 100\% \]  
\[ \text{... Detection Quality} \]  

\[ N_n: \# \text{ of the actual non-ZQBs} \]  
\[ N_m: \# \text{ of the miss-detected ZQBs} \]  
\[ N_z: \# \text{ of the actual ZQBs} \]  
\[ N_f: \# \text{ of the false-detected ZQBs} \]
## Experimental Results

### PSNR / Detection rate, *Akiyo*

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<td>DR</td>
<td>$\Delta P$</td>
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<td>62.4</td>
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<td>0.037</td>
<td>98.2</td>
<td>0.032</td>
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Experimental Results

PSNR / Detection rate, *Foreman*

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<td>46</td>
<td>-0.016</td>
<td>96.6</td>
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Detection Quality

- Akiyo
  - Xie2007
  - Wang2007
  - Proposed

- Foreman
  - Xie2007
  - Wang2007
  - Proposed
Experimental Results

Computation saving rate

\[ CSR(\%) = (1 - \frac{OP}{OP_{org}}) \times 100\% \]
Conclusions

- An insignificant PSNR degradation
  - On average, 0.08 dB drop of our algorithm.
- Higher detection ratio
  - On average, 90% of detection ratio.
  - Especially encoding at lower QPs (high bit-rate coding)
- Computational savings
  - Up to 54.6% of DCT/Q/IQ/IDCT computations can be reduced by using our method.
Thank you for your listening.