Low-complexity video compression based on 3-D DWT and fast entropy coding

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Problem definition

Scalable video coding (SVC) is the most preferable compression method for video transmission over wireless networks with time-varying bandwidth and packet losses.

Scalable video stream includes several layers:

- *base layer* is always coded independently and provide basic visual quality with low bit-rate.
- *enhancement layers* provide refinement quality and higher bit rate.

Scalable video stream provides:

- robust transmission due to unequal error protection of different layers[1];
- bandwidth adaptation due to dropping the higher enhancement layers[2].

[1] M.Gallant and F. Kossentini, "Rate-distortion optimized layered coding with unequal error protection for robust Internet video", 2001.

[2] Y.P. Fallah, H. Mansour, S. Khan, P. Nasiopoulos, H.M. Alnuweiri, "A Link Adaptation Scheme for Efficient Transmission of H.264 Scalable Video Over Multirate WLANs", 2008.

Problem definition

Currently the most popular scalable video coding approach is an extension of the H.264/SVC standard[1] which provides high compression efficiency due to motion compensation and inter-layer prediction. But, because of high computational complexity of these methods, implementation of H.264/SVC encoder in a mobile device is a difficult task.

As an alternative the scalable video coding based on three-dimensional discrete wavelet transform (3-D DWT)[2] have been proposed. This approach

- do not use motion estimation,
- but has highly complex entropy encoder.

3-D DWT codec complexity can be further decreased by development of the new low-complexity entropy coding methods.

[1] H. Schwarz, D.Marpe, and T.Wiegand, "Overview of the Scalable Video Coding Extension of the H.264 / AVC Standard", 2007.

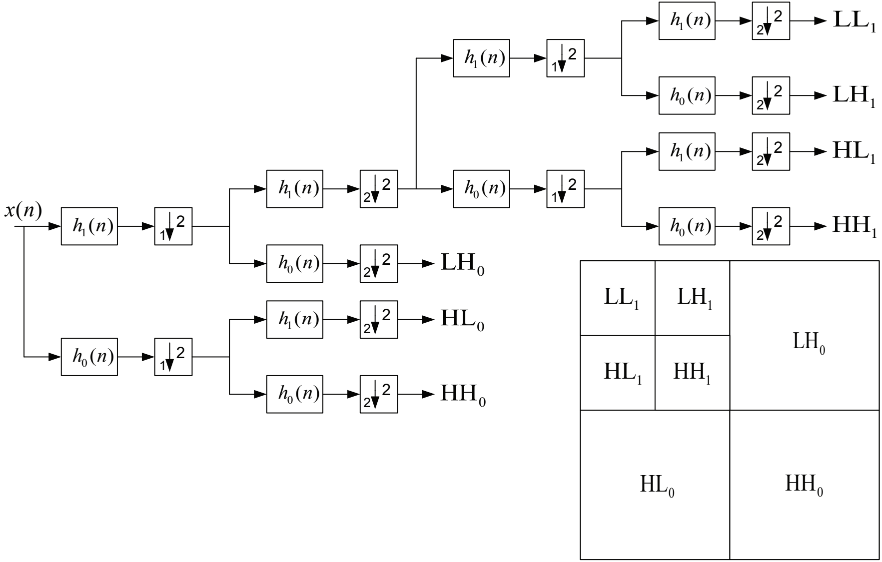
[2] B.J. Kim, Z. Xiong, and W. A. Pearlman, "Low bit-rate scalable video coding with 3-D set partitioning in hierarchical trees (3-D SPIHT)", 2000.

Main encoding stages

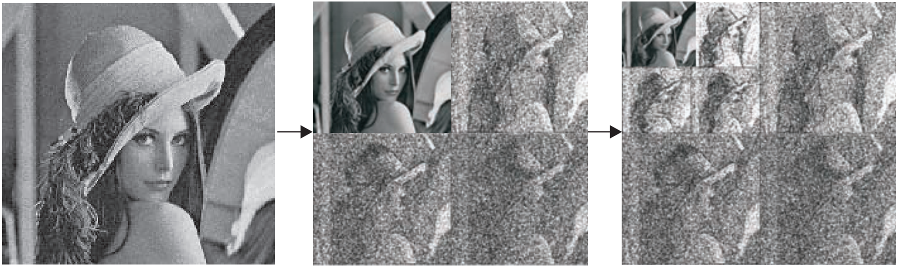
3-D DWT based video compression algorithm includes:

- Spatial two-dimensional discrete wavelet transform;
- One-dimensional discrete wavelet transform in temporal direction;
- Quantization of wavelet coefficients;
- Bit-plane entropy encoding of each wavelet matrix.

Two-dimensional discrete wavelet transform



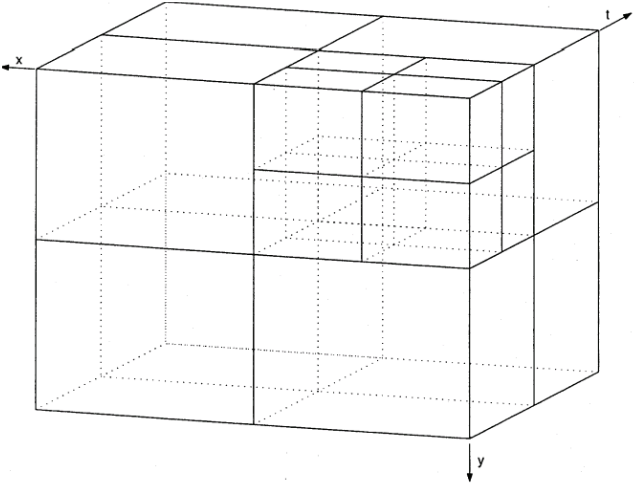
L-levels two-dimensional discrete wavelet transform



For each frame we have $(3 \times L + 1)$ wavelet matrix.

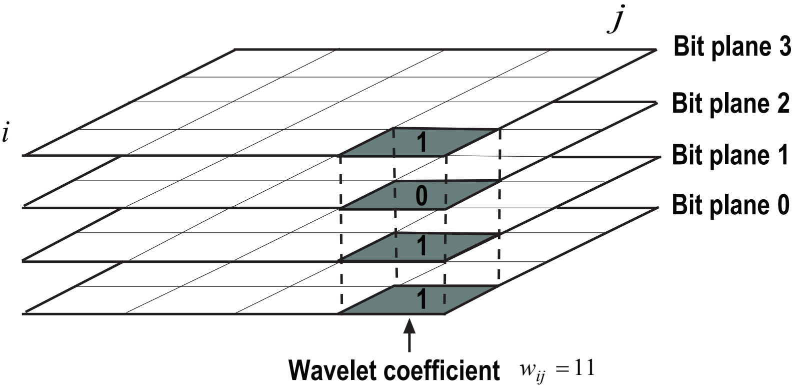
Discrete wavelet transform in temporal direction

We accumulate n frames (group of frames, GOP) and calculate wavelet transform in temporal direction.



Thus, for each GOP we have $(3 \times L + 1) \times n$ wavelet matrix.

Bit-plane entropy encoding of a wavelet matrix



- Quantity of non-zero bit-planes Q is compressed.
- Bit-planes are compressed starting from bit-plane $Q - 1$.
- All bits in each bit-plane are scanned from left to right and from top to bottom.

Bit-planes compression

- Each wavelet coefficient X has 8 neighbors which can be significant or insignificant. At the beginning all coefficients are insignificant.

D_0	V_0	D_1
H_0	X	H_1
D_2	V_1	D_3

1. If current coefficient and all neighbors are insignificant:
   - if current bit is 0, then zero-run counter N is increased by 1,
   - if current bit is 1, then zero-run counter N is compressed by Levenstein code and set to $N = 0$.
2. If at least one neighbor coefficient is significant and current coefficient is insignificant, then current bit is placed into output bit stream without compression.
3. If at steps 1 or 2 current bit was 1, then current wavelet coefficient X is placed into output bit stream without compression and become significant.

Zero-run compression by Levenstein codes

For compression of zero-run $\underbrace{000..0}_{N}1$, value N is represented by two parts:

1. Part 1:

$$\underbrace{\mathtt{binary\ representation\ of\ } c}_{\lfloor \log_2(\log_2 N_{max}) \rfloor + 1\ \mathtt{bits}},$$

   where

$$c = \begin{cases} 0, \text{ if } N = 0 \\ \lfloor \log_2 N \rfloor + 1, \text{ if } N > 0, \end{cases}$$

   N_{max} is maximum possible zero-run value.

2. Part 2: (if $c \geq 2$)

$$\underbrace{\mathtt{binary\ representation\ of\ } N - 2^{c-1}}_{c - 1\ \mathtt{bits}}.$$

Practical results

Codec	Description
x.264[1]	The fastest software implementation[2] of H.264/AVC encoder (in *-ultrafast* mode)
3-D SPIHT[3]	3-D DWT codec implementation with entropy encoder with 3-D set partitioning in hierarchical trees[4] proposed by W. A.Pearlman
3-D DWT Arithmetic	3-D DWT codec implementation with bit-plane entropy encoder based on binary adaptive range coder and context modeling in JPEG2000 style.
3-D DWT Levenstein	3-D DWT codec implementation with bit-plane entropy encoder based on Levenstein codes

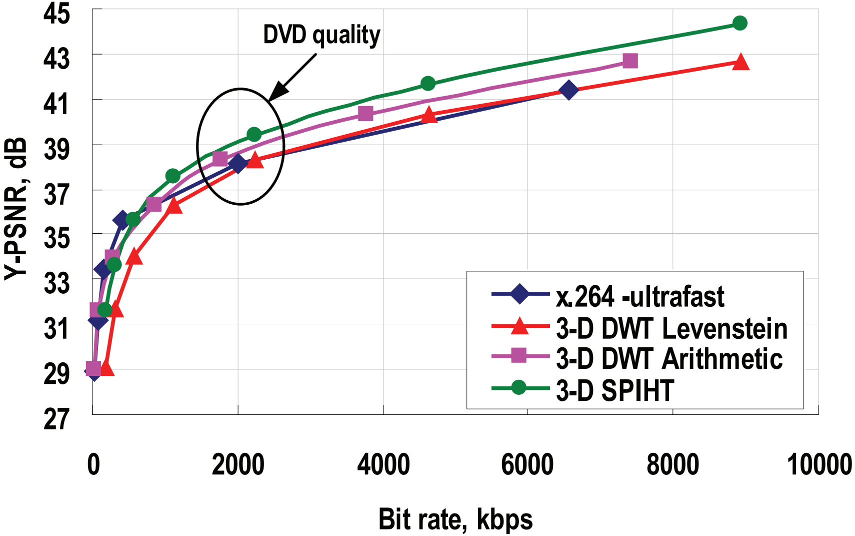
[1] http://www.videolan.org/developers/x264.html

[2] http://compression.ru/video/codec_comparison/

[3] http://ipl.rpi.edu/research/SPIHT/spiht3.html

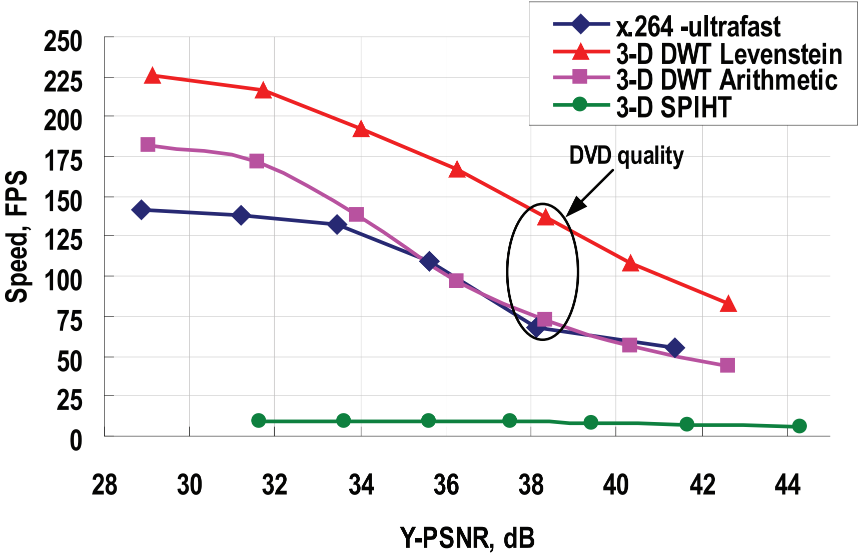
[4] B.J. Kim, Z. Xiong, and W. A. Pearlman, "Low bit-rate scalable video coding with 3-D set partitioning in hierarchical trees (3-D SPIHT)", 2000.

Rate-Distortion comparison[1]



[1]Test video sequence: vassar_0, 640×480, 30 fps.

Computation complexity comparison[1]



[1] All results were obtained for C-code software implementations without assemblers, GPU optimization etc. for processor Intel Core 2 Duo 3.6 GHz