Adaptive Interpolation Filter for Motion and Aliasing Compensated Prediction

Thomas Wedi

Institut fuer Theoretische Nachrichtentechnik und Informationsverarbeitung
University of Hannover, Appelstr. 9a, 30167 Hannover, Germany
wedi@tnt.uni-hannover.de

ABSTRACT

Common motion compensated hybrid video coding standards such as H.263, MPEG-1, MPEG-2, MPEG-4 are based on a fractional-pel displacement vector (DV) resolution of 1/2-pel. Recent approaches like MPEG-4 (ACE-profile) and H.26L use higher DV resolutions of 1/4-pel and 1/8-pel. In order to estimate and compensate fractional-pel displacements, the image signal has to be interpolated. Especially for higher DV resolutions an efficient interpolation filter is necessary [13]. Thus, in MPEG-4 (ACE-profile) and H.26L 6 or 8-tap Wiener interpolation filters are applied [5,3]. These Wiener filters were designed to interpolate the image signal while reducing spacial aliasing components that deteriorate the motion compensated prediction [6]. In [12] we presented an improved interpolation filter that allows to interpolate an aliasing affected image more accurate then the conventional Wiener filter. This filter is a combination of the Wiener filter and a motion compensated interpolation filter. Up to now these filters are based on invariant filter coefficients. The same coefficients are applied for all sequences and for all images of a sequence. In [10] we presented an adaptive interpolation filter that improves the coding efficiency by reducing the impact of displacement estimation errors and by compensating the aliasing components. The interpolation scheme of [10] is based on filter coefficients that are adapted once per frame to the non-stationary statistical features of the sequence. This paper introduces a motion compensated adaptive interpolation filter that combines the frame-adaptive approach of [10] and the motion compensated interpolation approach of [12]. Due to the motion compensated adaptive interpolation filter, the coding efficiency of an H.26L codec is improved up to 0.8 dB.

Keywords: video coding, H.26L, MPEG, motion compensated prediction, aliasing compensation, adaptive interpolation

1. INTRODUCTION

Standardized hybrid video coding schemes like H.263, MPEG-2, MPEG-4 etc. are based on motion compensated prediction [2,4,5]. Figure 1 shows the generalized block diagram of such an hybrid video encoder, where the current frame to be

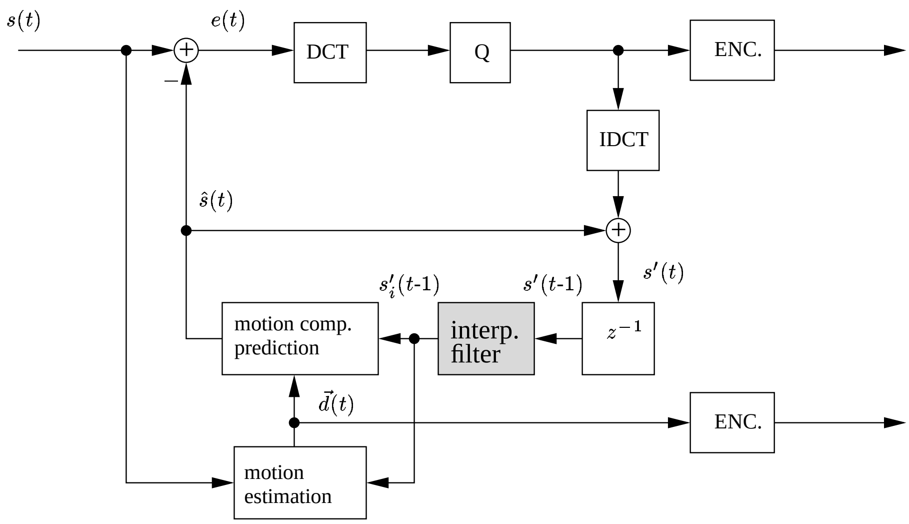


Figure 1. Generalized block diagram of a hybrid video encoder based on motion compensated prediction.

Proc. Electronic Imaging 2002: Visual Communications and Image Processing (VCIP), San Jose, CA, USA, Jan. 2002

coded $s(t)$ is predicted by a motion compensated prediction from an already reconstructed image $s'(t\text{-}1)$. The result of the motion compensated prediction is image $\hat{s}(t)$. Only the prediction error $e(t)$=$s(t)$-$\hat{s}(t)$ and the motion information $\vec{d}(t)$ are coded and reconstructed. For the motion compensated prediction purpose, the current image is partitioned into blocks. A displacement vector $\vec{d}(t)$ is assigned to each block that refers to the corresponding position of its image signal in an already transmitted reference image. The displacement vectors are abbreviated with DV. The DVs have a fractional-pel resolution, and therefore may refer to a position in a reference image that is located between the sampled positions of its image signal (sub-pel positions). In order to estimate and compensate fractional-pel displacements, the image signal on these sub-pel positions has to be generated by interpolation. The coefficients of an interpolation filter weight the image signal at the sampled positions (full-pel positions) in order to generate the image signal at sub-pel positions. The interpolated image is denoted as $s_i'(t\text{-}1)$.

Due to non-ideal low-pass filters in the image acquisition process, the *Nyquist Sampling Theorem* is not fulfilled and aliasing disturbs the motion compensated prediction [1]. This leads to a prediction error, which has to be coded. Thus, recent video coding standards like MPEG-4 (ACE-profile) and H.26L apply Wiener interpolation filters [5,3]. These filters were designed to interpolate the image signal while reducing aliasing components, which deteriorate the motion compensated prediction [6]. In the following these kind of Wiener filters are denoted as Wiener filters. These Wiener filters weight the image signal on the sampled positions of the image to interpolate $s'(t\text{-}1)$ in order to create the sub-pel values of image $s_i'(t\text{-}1)$. Up to now these Wiener filters are based on invariant filter coefficients. The same coefficients are used for all sequences and for all frames of a sequence.

In [12] we presented a *Motion Compensated Interpolation* (MCI) filter that allows to interpolate an aliasing affected image more accurate then the conventional Wiener filter. This filter is a combination of the Wiener filter and a motion compensated filter. It does not only use the image signal of the frame to be interpolated, but also the image signal of previous frames for the interpolation purpose. It is shown in [12] that for certain features of the image signal, the motion compensated prediction with this filter could be done perfectly, even if the image signal is affected by aliasing. The filter does not only utilize samples of the frame to interpolate $s'(t\text{-}1)$, but also the motion compensated samples from the interpolated frame at time instance t-2 in order to interpolate frame $s_i'(t\text{-}1)$. This motion compensated interpolation is performed with DVs $\vec{d}(t\text{-}1)$ that are already estimated in the *motion estimation* module (Fig. 1). One disadvantage of this scheme is the sensitivity concerning DV estimation errors. Since the filter is a motion compensated filter that uses displacement vectors for the interpolation purpose, the efficiency depends on the accuracy of the DV estimation. High DV estimation errors may lead to a less efficient coding result.

In [10] we presented an *Adaptive Interpolation* (AI) filter in order to improve coding efficiency. This interpolation filter is based on filter coefficients that are adapted once per frame to the non-stationary statistical features of the sequence. Similar to the non-adaptive Wiener filter, these adaptive coefficients weight the image signal on the sampled positions of the image to interpolate $s'(t\text{-}1)$ in order to create the sub-pel values of image $s_i'(t\text{-}1)$. It is shown in [10] that an adaptive filter reduces prediction errors caused by displacement estimation errors and by aliasing. Since this adaptive filter did not use any information of previous frames, its capability of aliasing compensation is limited.

This paper introduces an interpolation filters that combines the frame-adaptive approach of [10] and the motion compensated interpolation approach of [12]. Therefore it is called *Motion Compensated Adaptive Interpolation* (MCAI) filter. The MCAI-Filter improves the coding efficiency by reducing the influences of DV estimation errors and therefore improves the aliasing compensation. In order to generate the image signal on sub-pel positions, the adaptive coefficients do not only weight the image signal of the frame to be interpolated $s'(t\text{-}1)$, but also those of previous already transmitted frames $(s'(t\text{-}1)$,$s'(t\text{-}2)$,...) in order to generate the image signal on sub-pel positions of $s_i'(t\text{-}1)$. Furthermore these coefficients are adapted once per frame to the non-stationary statistical features of the image sequence. These filters improve the coding efficiency by reducing the prediction error caused by aliasing and by displacement estimation errors.

In Section 2 the adaptive interpolation scheme of [10] and in Section 3 the motion compensated interpolation scheme of [12] is introduced. In Section 4 the new motion compensated adaptive interpolation scheme is presented. Experimental results are given in 5. The paper closes with a summary.

2. ADAPTIVE INTERPOLATION FILTER (AI-FILTER)

In [10] we presented an adaptive interpolation filter for motion compensated prediction. The filter scheme and the performance evaluations are given in the following subsections.

2.1. Filter Scheme of the Adaptive Interpolation

Figure 2 gives the *interpolation filter* block of Figure 1 in detail. It shows the block diagram of the interpolation process that is applied in MPEG-4 (ACE-profile) and H.26L for 1/4-pel displacement vector resolution. The image is sampled up in to steps.

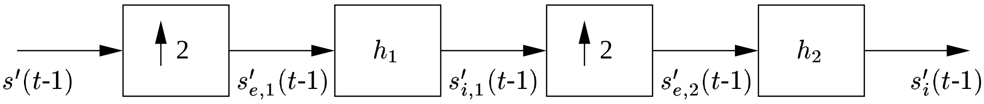


Figure 2. Interpolation scheme for 1/4-pel displacement vector resolution that is used in MPEG-4 ACE and H.26L. It is based on two steps with two interpolation filters h_1 and h_2

In the first step the resolution is increased by a factor of 2 and filtered by an interpolation filter h_1. In H.26L, filter h_1 is a 6-tap and in MPEG-4 h_1 is an 8-tap Wiener filter. In the second step the resulting image is again sampled up by a factor of 2 and filtered by an interpolation filter h_2. In H.26L and in MPEG-4, filter h_2 is a simple bilinear interpolation filter.

In the adaptive interpolation scheme from [10] filter h_1 is adapted once per frame ($h_1 = h_1(t)$). If it is assumed that h_1 is a symmetric 8-tap filter, only four filter coefficients have to be adapted. The motion compensated prediction with the adaptive interpolation filter consists of the following four steps:

1. Displacement vectors $\vec{d}(t)$ are estimated for the frame to be coded.
2. Filter coefficients are estimated by minimizing the energy of the prediction error $e(t)$=$s(t)$-$\hat{s}(t)$ when performing the motion compensated prediction with the displacement vectors $\vec{d}(t)$ from step 1.
3. The current frame is predicted by the motion compensated prediction. For this purpose the filter coefficients of step 2 and the displacement vectors of step 1 are applied.

In step 2 the coefficients of the adaptive interpolation filter are estimated once per frame. This is done by minimizing the energy of the prediction error $e(t)$=$s(t)$-$\hat{s}(t)$ when performing the motion compensated prediction with $\vec{d}(t)$. The image signal $s(t)$, the previously reconstructed image $s'(t\text{-}1)$, and the already estimated displacement vectors $\vec{d}(t)$ are considered. Thus aliasing in $s(t)$ and $s'(t\text{-}1)$, quantization errors in $s'(t\text{-}1)$, and DV estimation errors in $\vec{d}(t)$ are considered.

The adaptive character of this interpolation filter requires the transmission of their coefficients, because coder and decoder should apply the same filters for the motion compensated prediction. For this purpose, a differential coding scheme with a uniform 12 bit quantization is applied. This means that even for a fixed length code only $4 \cdot 12 = 48$ additional bits are necessary for each image.

2.2. Performance Analysis

There are three reasons why an adaptive interpolation filter reduces the remaining prediction error and improves the coding efficiency.

The first reason is the consideration of varying displacement estimation errors. A displacement estimation error leads to an inaccurate displacement vector, which means that the displacement vector refers to an inaccurate spatial position in a reference image. Due to this inaccurate spatial position a prediction error remains, which has to be coded. If this inaccurate spatial position is a sub-pel position, an optimal interpolation filter should consider the inaccuracy of the displacement vector in order to reduce the prediction error. The accuracy of an estimated displacement vector depends on the motion compensated prediction technique and on the image content. Since the image content differs from scene to scene, the displacement estimation error also differs. An invariant interpolation filter as it is used up to now cannot consider these varying displacement estimation errors. Since the DVs are considered in the coefficient estimation process of AI-filter scheme, the AI-filter reduces the influence of the DV estimation errors on the motion compensated prediction. Analytical calculations and experimental results in [10] show that the higher the variance of the displacement estimation error is, the more low-pass characteristic the adaptive interpolation filter has. Thus, the prediction error of the motion compensated prediction is reduced and the coding efficiency is improved.

The second reason, why to use an adaptive interpolation filter, is the consideration of varying aliasing signals. Due to non-ideal low-pass filters in the image acquisition process, the Nyquist Sampling Theorem is not fulfilled and aliasing disturbs the motion compensated prediction [1]. This leads to an additional prediction error, which has to be coded. Since the non-ideal low-pass filters differ for various image acquisition processes, the aliasing also differs. An invariant interpolation filter as it is used up to now cannot consider these varying aliasing components. Since the input signal $s(t)$ and the reconstructed frame $s'(t\text{-}1)$ are considered in the coefficient estimation process of AI-filter scheme, the AI-filter reduces influence of aliasing on the motion compensated prediction. Thus, the prediction error of the motion compensated prediction is reduced and the coding efficiency is improved.

The third reason why an adaptive interpolation filter reduces the remaining prediction error and improves the coding efficiency is the consideration of quantization errors. The motion compensated prediction is based on the reconstructed frame $s'(t\text{-}1)$. Thus, quantization errors disturb the prediction process. Since frame $s'(t\text{-}1)$ is considered in the coefficient estimation process, the influence on quantization errors on the motion compensated prediction is reduced.

The results in [10] and [11] show a gain of up to 1 dB PSNR with the adaptive interpolation filter compared to the non-adaptive Wiener interpolation filter.

3. MOTION COMPENSATED INTERPOLATION FILTER (MCI-FILTER)

In [12] we presented a motion compensated interpolation scheme for motion and aliasing compensated prediction. The filter scheme and the performance evaluations are given in the following subsections.

3.1. Filter Scheme of the Motion Compensated Interpolation

Figure 3 shows an example of a motion compensated interpolation of $s_i'(t\text{-}1)$ and prediction of the current frame $\hat{s}(t)$. In order to simplify the description, the 2D frames are reduced to 1D image lines. Furthermore the example is based on DV resolution of 1/2-pel. Fig. 3 shows samples and undetermined sub-pel values of corresponding image lines of subsequent time instances.

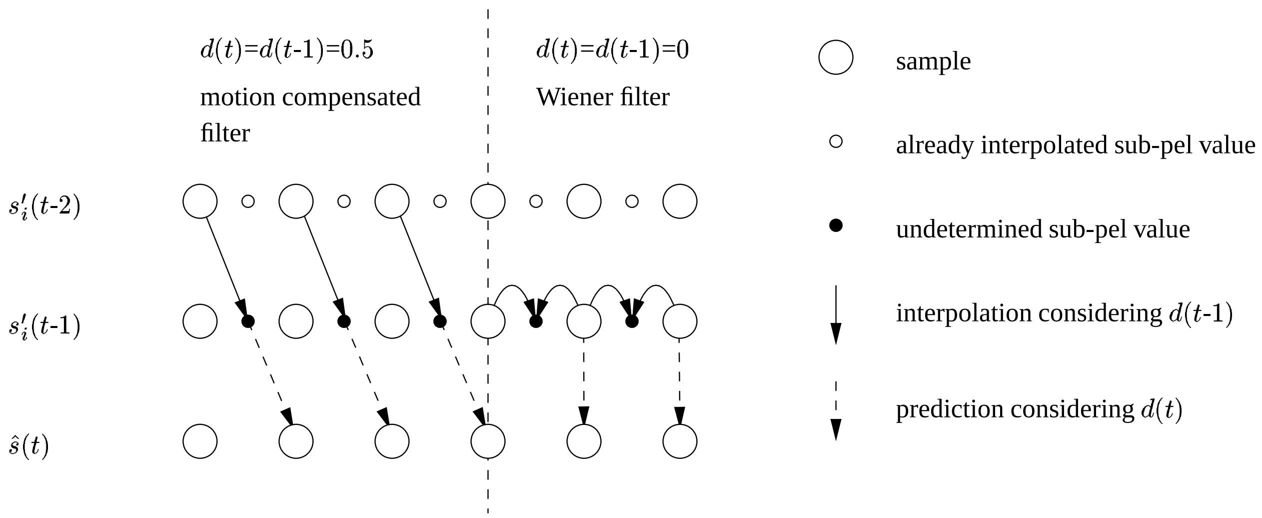


Figure 3. Example of a motion compensated interpolation (based on 1/2-pel DV resolution) of $s_i'(t\text{-}1)$ and prediction of the current frame $\hat{s}(t)$. Corresponding lines of the following subsequent frames are shown: the frame to predict $\hat{s}(t)$, the frame to interpolate $s_i'(t\text{-}1)$ and the previous interpolated frame $s_i'(t\text{-}2)$.

The undetermined sub-pel values have to be generated by interpolation. This interpolation process is denoted by solid arrows. The dashed arrows denote the prediction, which uses the interpolated frame $s_i'(t\text{-}1)$ and the DVs $\vec{d}(t)$in order to generate the prediction frame $\hat{s}(t)$. In the left part of these lines it is assumed that the displacement is $d(t) = d(t\text{-}1) = 0.5$. In the right part a displacement of $d(t) = d(t\text{-}1) = 0$ is assumed. In the left part, the displacement of $d(t\text{-}1) = 0.5$ denotes that the corresponding position of the undetermined values of frame $s'_i(t\text{-}1)$ are full-pel samples in frame $s'_i(t\text{-}2)$. Therefore the motion compensated interpolation uses the corresponding full-pel samples in order to interpolate the undetermined values. If these interpolated values are used for the prediction purpose (dashed arrows), a former full-pel sample is used in order to predict image $s(t)$. Thus the image signal including their aliasing components may be predicted. In the right part, the displacement denotes that the corresponding position of the undetermined values are also undetermined values. In this case, the spacial Wiener filter is applied in order to interpolate the undetermined values.

3.2. Performance Analysis

The aliasing compensation idea of this interpolation filter is the following: If an unmoved, analog image signal is sampled at the same positions at different time instances, the two sampled signals are identical even if the sampling rate doesn't fit to the Nyquist frequency. Therefore the sampled images also have the same aliasing components. If the image signal is displaced by one sample, the corresponding, displaced samples are identical and have the same aliasing components. This shows, that at full-pel displacements the aliasing does not affect the prediction. Furthermore, it induces a new interpolation approach. If it is known that a signal is shifted by a fractional-pel displacement, we may insert the former samples from the full-pel positions at the corresponding sub-pel positions in the current upsampled image, knowing that they contain the correct sampled image signal. Even the aliasing components is predicted correctly.

Due to the fact that more than the current frame is considered in the interpolation process, it is possible to predict aliasing more accurate than with common interpolation filters. It is shown in [12] that the image signal including their aliasing components can be predicted perfectly, if no displacement estimation errors are present.

One disadvantage of this MCI-filter is the accumulation of displacement estimation errors. Since the previously estimated displacement vector field $\vec{d}(t\text{-}1)$ between $s'(t\text{-}2)$ and $s'(t\text{-}1)$ is applied in order to interpolate frame $s'(t\text{-}1)$, the displacement estimation errors introduce errors in the interpolation frame $s'_i(t\text{-}1)$. This interpolated frame is used in order to estimate the current displacement vector field $\vec{d}(t)$ and in order to predict the frame to code. Thus, the displacement estimation errors accumulate. For high displacement estimation errors this simple MCI-filter may lead to a less efficient coding scheme.

4. MOTION COMPENSATED ADAPTIVE INTERPOLATION FILTER (MCAI-FILTER)

In order to exploit the advantages of the AI- and MCI-filters, and in order to reduce the problem of DV error accumulation in the MCI-filter, the MCI-filter scheme is extended to a motion compensated adaptive 3D interpolation filter. Thus the motion compensated prediction and the coding efficiency is improved.

Analogous to the example of the MCI-filter in Fig. 3, Fig. 4 shows an example of a motion compensated adaptive interpolation. In contrast to Fig. 3, in Fig. 4 the interpolation process for only one specific undetermined sub-pel value is shown.

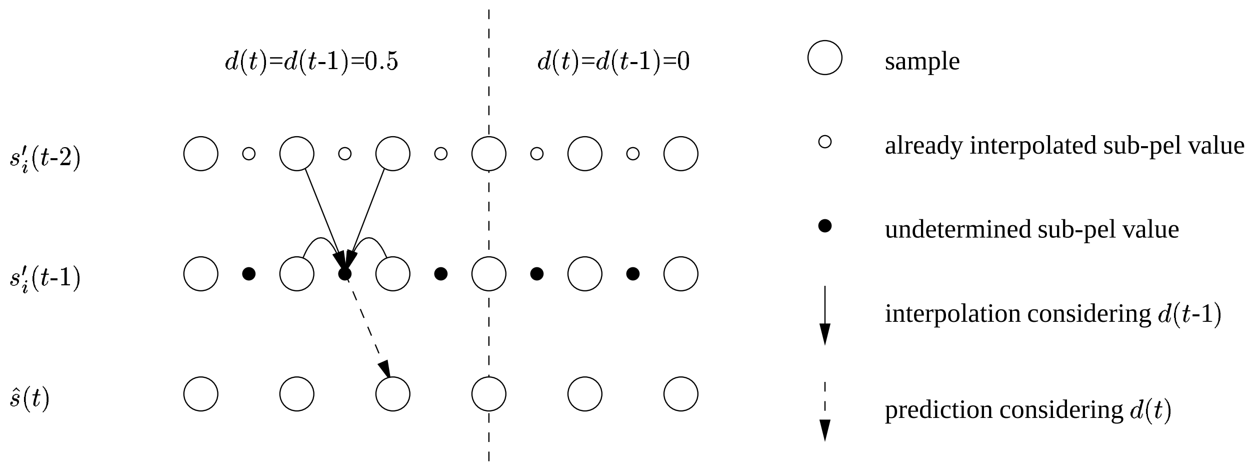


Figure 4. Example of a motion compensated adaptive interpolation of $s'_i(t\text{-}1)$ for one special undetermined sub-pel value. In this example 1/2-pel DV resolution is assumed. Corresponding lines of the following subsequent frames are shown: the frame to predict $\hat{s}(t)$, the frame to interpolate $s'_i(t\text{-}1)$ and the previous interpolated frame $s'_i(t\text{-}2)$.

Each solid arrow denotes an adaptive filter coefficient that weights the image signal on the sampled positions in order to create the undetermined sub-pel value. These coefficients are adapted once per frame. In contrast to the non-adaptive motion compensated interpolation from figure 3, where the previous samples are just inserted, they are filtered in the MCAI filter. The result is a 2D-filter, which also has a filter dimension in the temporal direction. In the example of Fig. 4 two samples in the spacial direction ($N_x = 2$) and two samples in the temporal direction ($N_t = 2$) are taken into account. If this 2D filter with $N_x \times N_t = 2 \times 2$ for successive lines is extended to successive images, the result is a 3D filter with $N_x \times N_y \times N_t = 2 \times 2 \times 2$ filter coefficients. Larger Filters of $4 \times 4 \times 4$, $6 \times 6 \times 6$, ... are performed analogically.

In figure 5 two graphs of a part of a sampling grid of an image to interpolate is shown. In this Figure 1/4-pel DV resolution is assumed and 15 possible relative positions of undetermined values are shown. The numbers at these positions denote the

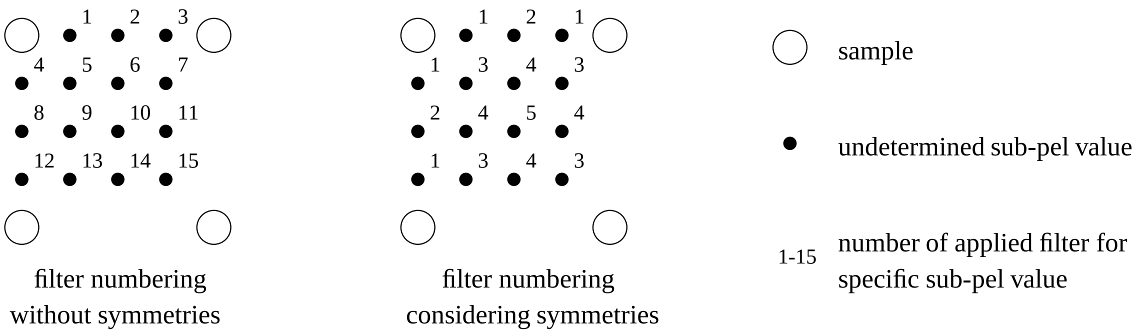


Figure 5. Part of a sampling grid of $s'_i(t\text{-}1)$ assuming 1/4-pel DV resolution. Each number represents an interpolation filter that is applied to generate the specific undetermined sub-pel value. Left: numbering without symmetry assumption, Right: numbering with symmetry assumption.

interpolation filter that is used in order to generate the image signal on the specific sub-pel positions. On the left part this numbering is done without any symmetry assumptions. In this case, 15 different 3D filters have to be estimated and transmitted. On the right part, the numbering is done by considering symmetries in the sampling grid. Thus, only 5 different filters have to be transmitted. The corresponding filters can be calculated by mirroring one of the 5 filter kernels. In case of a $4 \times 4 \times 4$ filter, $5 \cdot 4 \cdot 4 \cdot 4 = 320$ filter coefficients have to be estimated and transmitted for each frame.

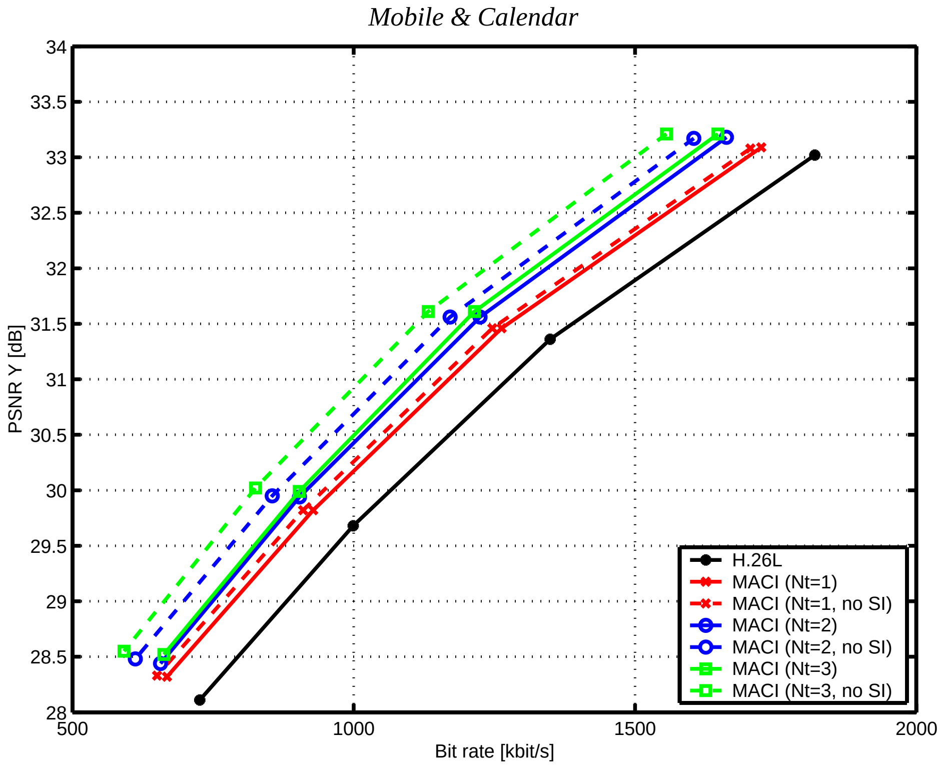
In the right part of Fig. 5 symmetries in the sampling grid are considered in order to reduce the number of different coefficients. A further reduction is achieved by considering symmetries of the filter-kernels itself. This leads to a further significant reduction of the number of filter coefficients to estimate and transmit.

The motion compensated prediction with the MCAI-filter is similar to the one of the AI-filter. The MCAI-filter coefficients are estimated by minimizing the prediction error $e(t)$=$s(t)$-$\hat{s}(t)$. Since the DVs $\vec{d}(t)$, $\vec{d}(t\text{-}1)$, ... are considered in the coefficient estimation process, the DV estimation errors and their accumulation is considered. Thus, the motion and aliasing compensated prediction is significantly improved.

5. EXPERIMENTAL RESULTS

The motion compensated adaptive interpolation filter has been integrated in the reference H.26L codec (TML-4) that applies a displacement vector resolution of 1/4-pel. The filter has been tested on the sequences "Mobile & Calendar" and "Flower Garden", each at CIF format and with a frame rate of 30 fps.

Figure 6 shows the operational rate-distortion curves for various sizes of adaptive interpolation filters, as well as the reference H.26L codec with the Wiener filter. The size of the filter is defined by three values: N_x, N_y (number of pels that are weighted in each frame) and N_t (number of previous frames taken into account). All of the MCIA curves are for a fixed spacial filter size of $N_x \times N_y = 4 \times 4$ and a varying temporal size of N_t=$1, 2, 3$. Thus the influence of increasing number of previous frames in the MCAI-filter on the coding efficiency can be analyzed. The dashed lines represent the results when no additional side information (SI) is transmitted. They are included to show to which extent the adaptive filters enhance the prediction.



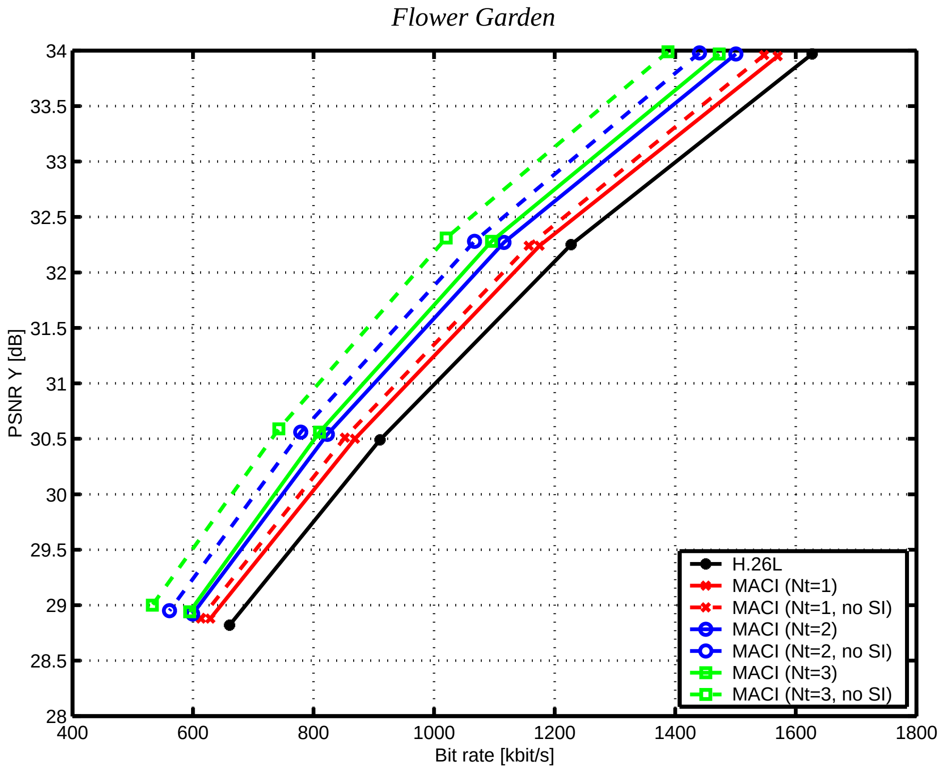


Figure 6. Operational rate distortion curves for the different interpolation filters for test sequences *Mobile & Calendar* and *Flower Garden*. Each MCAI-filter is based on $N_x \times N_y = 4 \times 4$. The dashed lines represent the results without the amount of additional side information (SI) for the filter coefficients.

The experimental results show a gain up to 0.8 dB PSNR for the MCAI filter with a size of $N_x \times N_y \times N_t = 4 \times 4 \times 3$ compared to the reference H.26L codec. Significant gains up to 0.4 dB PSNR are achieved by using $N_t > 1$ instead of $N_t = 1$, i.e. using 3D MCAI-filter instead of a 2D AI-Filter ($N_t = 1$) without motion compensated interpolation. Hypothetical gains up to 1.2 dB can be attained, if the additional side information is not considered. This clearly indicates improved prediction introduced by the MCAI-filter.

The gain of the MCAI-Filter with $N_t = 1$, which corresponds to a 2D AI Filter without motion compensated interpolation, compared to the results of [10] is smaller. This is due to the fact, that the filter length of the adaptive filter in [10] is higher (8-tap) compared to the 2D 4×4 MCAI-filter. Furthermore the amount of additional side information for the transmission of the filter coefficients is much higher than in [10]. In contrast to the adaptive interpolation scheme from [10], where one symmetric 1-D filter is adapted, in this contribution five 3D-filters are adapted once per frame. Since the motion compensated adaptive 3D-filter could be reduced to a symmetric 2D filter, this amount of additional side information could be significantly reduced.

6. CONCLUSIONS

An adaptive interpolation filter for motion and aliasing compensated prediction is presented. It is a motion compensated adaptive interpolation filter that applies samples of the frame to interpolate and motion compensated samples of previous frames for the interpolation purpose. Thus aliasing is compensated more precise than with conventional Wiener filters, which are applied in MPEG-4 and H.26L. The motion compensated filter is based on coefficients that are adapted once per frame to the non-stationary statistical features of the image sequence. The coefficient estimation is done by minimizing the error of the whole motion compensated prediction. Thus displacement estimation errors, aliasing, and quantization errors are considered.

The motion compensated adaptive interpolation filter has been integrated in the reference H.26L codec (TML-4) that applies a displacement vector resolution of 1/4-pel. Due to the motion compensated adaptive filter a gain up to 0.8 dB is obtained. A further significant gain could be obtained, if the number of filter coefficients that have to be transmitted is further reduced. This will be done in future work.

REFERENCES

1. A.V. Oppenheim, R.W. Schaefer, ”Discrete-Time Signal Processing”, Prentice Hall, ISBN 0-13-216292-X, 1989.
2. ITU Telecom. Standardisation Sector of ITU, ”Video coding for low bitrate communication”, ITU-T Recommendation H.263; Version 1, Nov. 1995; Version 2, Jan. 1996
3. ITU-T SG16/Q15 (G. Bjontegaard), ”H.26L Test Model Long Term Number 5 (TML-5)”, ITU-T SG16/Q15 doc. Q15-K-59, (downloadable via ftp://standard.pictel.com/video-site), Aug. 2000
4. MPEG-4: ISO/IEC, ”Final Committee Draft for ISO/IEC 14496-2”, Doc. ISO/IEC/JTC1/SC29/WG11 N2202, March 1998.
5. MPEG-4: ISO/IEC, ”Final Proposed Draft Amendment 1 for ISO/IEC 14496-2”, Doc. ISO/IEC/JTC1/SC29/WG11 N2802, Vancouver, July 1999.
6. O. Werner, ”Drift analysis and drift reduction for multiresolution hybrid video coding”, Signal Processing: Image Communication, Vol. 8, No. 5, July 1996, p.387-409, ISSN: 0923-5965
7. U. Benzler, O. Werner, ”Improving multiresolution motion compensating hybrid coding by drift reduction”, Picture Coding Symposium 1996, March 1996, Melbourne.
8. MPEG-4: ISO/IEC (U. Benzler), ”Results of core experiment P8 (Motion and Aliasing Compensated Prediction”, Doc. ISO/IEC/JTC1/SC29/WG11 N2625, October 1997.
9. ITU-T SG16/Q15 (T. Wedi), ”Motion and Aliasing Comensated pCompensatedfor H.26L”, ITU-T SG16/Q15 doc. Q15-i-35, (downloadable via ftp://standard.pictel.com/video-site), Oct. 1999
10. T. Wedi, ”Adaptive Interpolation Filter for Motion Compensated Hybrid Video Coding,” Picture Coding Symposium (PCS 2001), Seoul, Korea, April 2001.
11. ITU-T SG16/Q15 T. Wedi, ”Adaptive Interpolation Filter for H.26L”, ITU-T SG16/Q6 (VCEG) doc. VCEG-N28, (downloadable via ftp://standard.pictel.com/video-site), Sep. 2001
12. T. Wedi, ”A Time-Recursive Interpolation Filter for Motion Compensated Prediction Considering Aliasing,” International Conference on Image Processing (ICIP 1999), Kobe, Japan, October 1999.
13. T. Wedi, ”Hybrid Video Coding Based on High-Resolution Displacement Vectors”, Electronic Imaging 2001: Visual Communications and Image Processing (VCIP 2001), San Jose, California USA, January 2001