Vector-based Postprocessing of MPEG-2 Signals for Digital TV-Receivers

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ABSTRACT

Digital transmission of video signals and block-based coding/decoding schemes produce new artifacts such as Blocking, Dirty Window, Ringing and Mosquite Effects. These artifacts become worse with decreasing MPEG-2 data rates. Therefore the reduction of MPEG-artifacts becomes an attractive feature for digital TV-receivers. On the other hand an important feature for digital receivers is the performance of their postprocessing techniques such as object recognition, motion estimation, vector-based upconversion and noise reduction on MPEG-signals which are decoded in a receiver-based module called 'Set Top Box'.

In this paper different models dealing with the interaction between 'Set Top Box' and digital receiver are discussed. Hereby the influence of MPEG-artifacts on postprocessing methods is studied and methods for combining MPEG-2 decoding, artifact removal and postprocessing are presented.

A vector-based upconversion algorithm which applies nonlinear center weighted median filters (CWM) is presented. Assuming a 2-channel model of the human visual system (HVS) with different spatio temporal characteristics, errors of the separated channels can be orthogonalized and avoided by an adequate splitting of the spectrum. Hereby a very robust vector error tolerant upconversion method which significantly improves the interpolation quality is achieved.

This paper describes also a concept for temporal recursive noise and MPEG-artifact filtering on TV images based on visual noise perception characteristics. Different procedures in the spatial subbands lead to results well matched to the requirements of the human visual system. Using a subband-based noise filter temporally non correlated MPEG-artifacts can significantly be reduced.

Image analysis using object recognition for video postprocessing becomes more important. Therefore a morphological, contour-based mutilevel object recognition method which even stays robust in strongly corrupted MPEG-2 images is also introduced.

KEYWORDS

MPEG-2
Postprocessing
MPEG-2 Artifacts
Artifact Reduction
Motion Estimation
Upconversion
Noise Reduction
Spatial Subband Processing
Object Recognition
Morphological Erosion

1 INTRODUCTION

A lot of applications in the field of digital video signal processing have become feasible due to progress in modern microelectronics.[12] Postprocessing techniques are carried out in a digital receiver on video signals which were transmitted analogously in order to enhance the picture quality. Object recognition, motion estimation, motion vector-based scan rate conversion and noise reduction are examples for these postprocessing techniques.

Today digital transmission of video signals comes up. Video data which is encoded within the MPEG-2 standard encoded is decoded in a receiver based module called 'Set Top Box'. But digital transmission and coding/decoding produce new artifacts which are different from that of an analogue transmission. These artifacts become worse with decreasing MPEG-2 data rates. Therefore the reduction of MPEG-artifacts becomes an attractive feature for a TV-receiver. On the other hand a most important question for any kind of digital receiver is the performance of its postprocessing techniques on decoded signals.

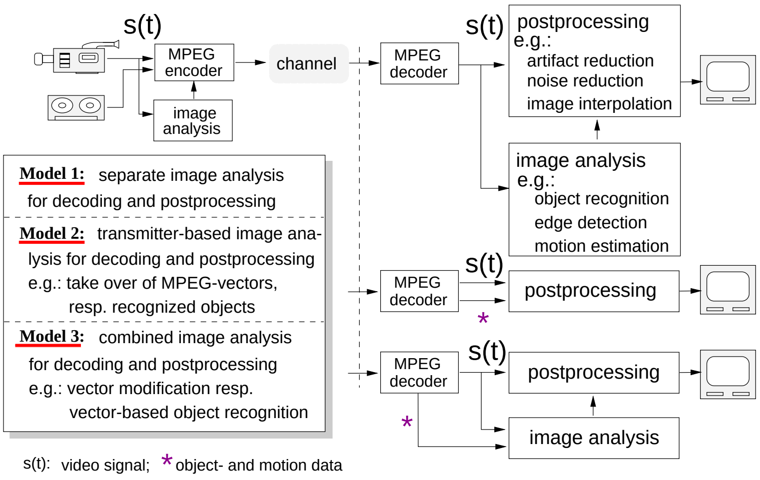


Figure 1: Several models for postprocessing at the receiver

Several models for receiver based postprocessing utilizing image analysis modules (e.g. MPEG-vectors) or utilizing own image analysis modules (e.g. own vectors) are possible. As can be seen in Fig. 1 several questions come up. On the transmitter as well as on the receiver side the influance of different motion estimation algorithm has been studied. On the transmitter side these motion vectors are required for MPEG encoding. On the receiver side MPEG decoding and e.g. vector-based upconversion requires vectors. Vector-based upconversion is an important fature to reduce annoying artifacts such as large area flicker or edge flicker.[4,6] Furthermore it can be investigated whether the MPEG-2 vectors can be used also for a receiver based postprocessing or if there are different demands concerning motion vectors for coding/decoding and postprocessing. Especially for integrated solutions in the future where today's 'Set Top Box' will be integrated in a digital receiver a direct use of MPEG-vectors (model 2) would be a great advantage. If the motion vector quality is not sufficient for postprocessing a further alternative would be to use the MPEG-2 vectors as prediction vectors for a vector update in the receiver which would result in less calculational costs than carrying out block matching again (model 3). The last alternative is to use dedicated motion estimation as well for coding/decoding as for receiver-based postprocessing (model 1). Furthermore it will be discussed if any kind of MPEG-artifact removal (e.g. blocking removal) should be carried out before further processing steps are applied. The PSNR (Peak Signal to Noise Ratio) which is a standard criterion for objective evaluation of image quality will be used in order to evaluate the different models.

Image analysis using object recognition for video postprocessing is an important step for high quality postprocessing techniques. Therefore the robustness of object recognition methods also in strongly corrupted MPEG-2 images should be guaranted. This aspect is also discussed in this paper. *In the end a system is presented which optimally combines MPEG-2 signals, artifact removel and postprocessing procedures for high picture quality demands.*

2 UPCONVERSION OF MPEG-2 TRANSMITTED SIGNALS

One important task in the field of digital video processing is the conversion of one standard into another with different field rates and scan rates. During the last years the demand for scan rate conversion was growing significantly as modern Multimedia-terminals have to convert different incoming video signals for different kinds of displays and therefore different kinds of reproduction standards. Especially on the European market field rate doubling is a very important feature for TV receiver applications as European present TV standard with 50 Hz interlace produces some annoying artifacts (50 Hz large area flicker, line crawling and 25 Hz edge flicker).

Within this section a class of upconversion algorithms which apply vector-based center weighted medians for a high quality upconversion also on MPEG-2 decoded signals is introduced.

2.1 Vector-based upconversion algorithms

Algorithms which carry out a norm conversion from one standard into another and which vary the spatio temporal sampling raster can be coarsely divided into the classes depicted in Fig. 2([13]). The two main streams are temporal interpolation and spatial interpolation. For both classes of interpolation examples are mentioned in Fig. 2.

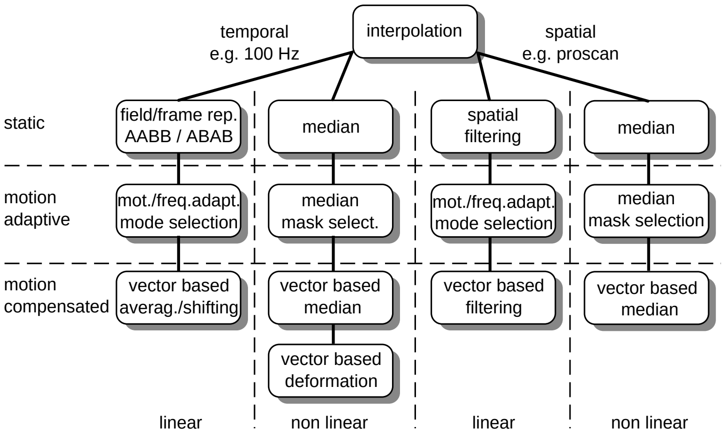


Figure 2: A classification of upconversion algorithms

Upconversion algorithms can be coarsely divided into static, motion adaptive and motion compensating ones and each of them can be further subdivided in linear and nonlinear ones depending on the type of filter which is applied. These classes of algorithms differ by the required hardware expense for the implementation (motion adaptive and motion compensating techniques require a higher implementation expense than static techniques) and by the interpolation quality which can be achieved. Generally the expense for the realization increases as well as the interpolation quality from the top of Fig. 2 to the bottom (a good review to the evolution of upconversion techniques is given in[4]). Motion portrayal in particular in case of critical scenes with complex motion and flicker reduction for high frequent picture parts are important criteria for evaluating an upconversion algorithm. A solution for these problems can only be achieved by motion vector-based algorithms, that means applying motion compensating techniques.[4] Vector-based algorithms can also be subdivided in linear and nonlinear techniques.

In[7] it could be shown that different vector-based linear interpolation techniques offer a different sensibility to motion vector defects. Vector-based algorithms which should achieve a higher interpolation quality than static algorithms because of their good motion portrayal sometimes produce worse results in case of critical scenes with complex motion. Errors in the motion vector fields which have been computed by a motion estimator are still a serious problem (principally no motion estimation algorithm is able to provide error free motion vectors). Therefore vector error tolerance of the interpolation scheme is essential for vector-based algorithms. Because of MPEG-artifacts in decoded video signals the motion vector quality decreases and this feature of vector error tolerance becomes more important for MPEG-Upconversion.

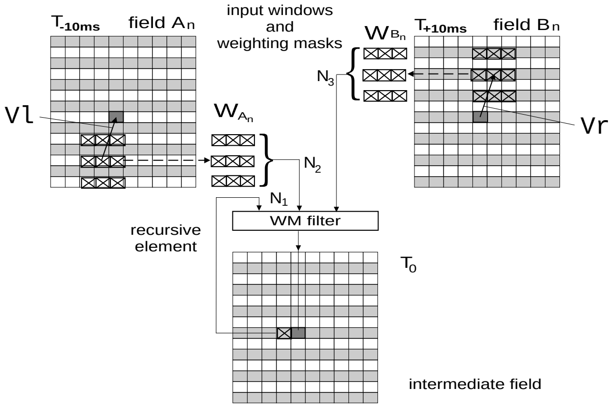


Figure 3: Interpolation scheme for the lows applying a vector addressed WM filter ($Vl = Vr = \frac{\vec{V}_{A_nB_n}}{2}$)

In[4] a new class of nonlinear vector and subband-based upconversion algorithm is described. One can see that the two types of median filters which are applied in this algorithm[4] meet the characteristics of the human visual system which can be described by a 2-channel model.[4] Therefore a vertical band separation is carried out. For the vertical highs a median filter is chosen which is temporally/interfield dominated and for the vertical lows a vertically/intrafield dominated median is adequate. The interpolation scheme for the lows applying a vector addressed WM filter is depicted in Fig. 3. The interpolation carried out by the Weighted Median filter (WM) can be formulated as

$$P_\beta(x,y,T_0) = \mathrm{med}\left(W_{A_n}\Diamond X_{A_n}(x,y,T_{-10\mathrm{ms}}); W_{B_n}\Diamond X_{B_n}(x,y,T_{10\mathrm{ms}}); W_{\beta_n}\Diamond X_{\beta_n}(x-1,y,T_0)\right) \tag{1}$$

The operator $\Diamond$ here denotes that the input samples within the masks (X_{A_n},X_{B_n}) will be weighted by the accompanying weighting masks (W_{A_n},W_{B_n}), that means that each value within these masks will be duplicated as much as the factor in W belonging to this value states. Because of the properties of the CWM filters objective and subjective tests in[4] showthat in comparison with other vector-based upconversion techniques the nonlinear upconversion algorithm applying weighted medians is the most robust one by existence of faulty vectors in particular by compelx object motions. In the next subsections the robustness of this algorithm on MPEG-2 signals will be discussed.

2.2 Simulation results for MPEG-upconversion

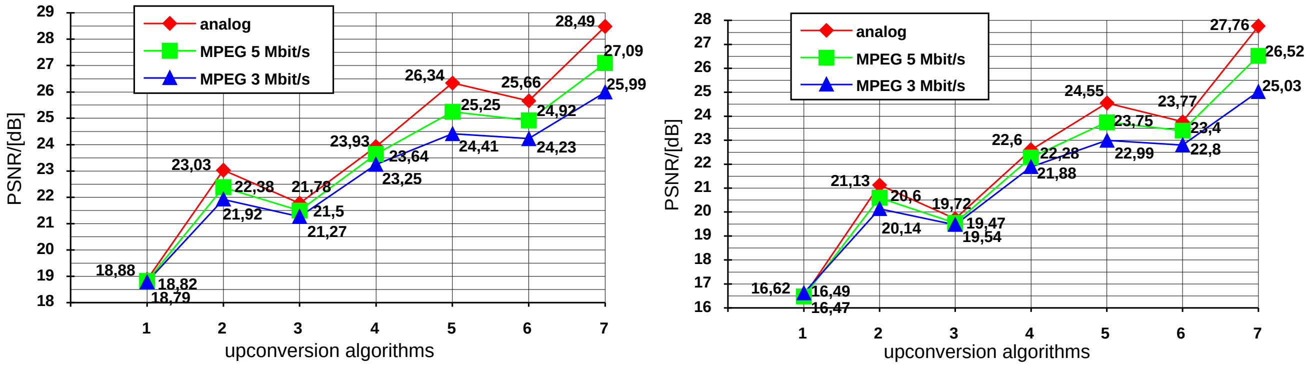
Within this subsection different models dealing with the interaction between 'Set Top Box' and digital receiver are discussed. In all simulations an MPEG Software coder/decoder of the MPEG Software Simulation Group was used. All simulations refer to the main profile/ main level with field size of 720x288 pixel, a luminance-chrominance ratio of 4:2:0 and a field rate of 50 fields/sec. The GOP (Group of Pictures) was set to a length of 12 (1 I-image, 3 P-images and 8 B-images). In the encoder a motion estimator, a full-search (FS) block-matching algorithm with quadratic error function and a so-called 'helical scan' (processing order of the search area in concentrical circles), was used. The search area was adjusted to ±16 pel with halfpel accuracy. As test sequences for this study the two sequences 'football' and 'wheel' were used. These sequences represent two kinds of complex motion, a camera zoom and a rotational motion.
Applicability of different upconversion algorithms to MPEG-transmitted signals: A first examination refers to the use of different upconversion algorithms in a receiver, which shall process MPEG transmitted and decoded image data in the same way as analogous transmitted image data. These test sequences were now transmitted analogously, via MPEG with a data rate of 5 Mbit/s resp. 3 Mbit/s and decoded in the receiver. Then, for each of the transmitted sequences a pure receiver-based upconversion was carried out. So this corresponds to model 1 in Fig. 1.

The upconversion algorithms used should represent a wide spectrum of the different classes of upconversion algorithms. The following algorithms have been examined:

1. frame repetition (ABAB)[13]
2. field repetition (AA'B'B)[13]
3. a combination of frame- and field repetition by a vertical band separation[13,12]
4. a static nonlinear upconversion technique[6]
5. a vector-based linear upconversion technique[7]
6. a vector-based 3-tap median technique[8]
7. a vector-based nonlinear upconversion technique using weighted median-filters[4]

The simulation results for the test sequences used are shown in Fig. 4. These results point out a common tendency, although they have different scale values

The ranking of the algorithms does not change when using MPEG-transmission, but the quality of the upconverted images decreases from analogous to MPEG-transmission and decreases with the MPEG data rate. It is obvious that the decreasing quality varies less for static algorithms than for vector-based algorithms. The reason for this is that the quality of the receiver-based motion estimation goes along whith the data rate. The stronger MPEG-artifacts appear in a decoded sequence, the more errors occur in the motion estimation. Erroneous vectors are caused for example by block structures which are part of the decoded images in case of low data rate. Despite of this lower variation inquality of the static algorithms it is obvious, that even with MPEG-transmitted data and low data rate, vector-based algorithms have clear advantages versus static algorithms. Even at 3 Mbit/s the



(a) 'football'

(b) 'BBC-wheel'

Figure 4: Simulation results of upconversion algorithms

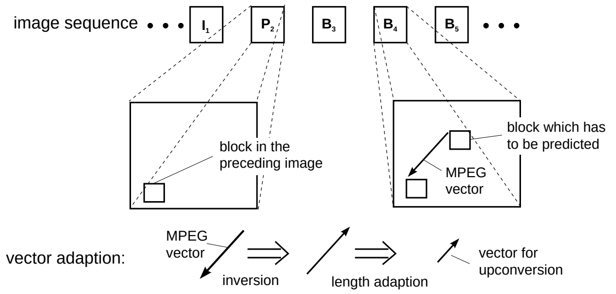


Figure 5: Adaption of the MPEG-2 vectors

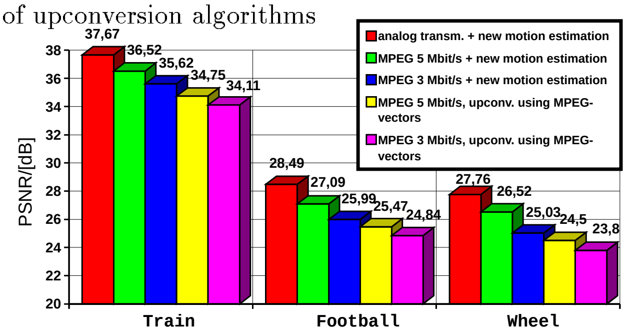


Figure 6: The quality of the interpolated sequences using MPEG-2 vectors

best vector-based algorithm[4] is about 2-3 dB better than the best static algorithm,[6] depending on the sequence. **Using MPEG-vectors for upconversion:** In an MPEG-2 coder, a block (16x16 pel) of an image is predicted from blocks of other (previous and following) images using transmitted vectors. The assumption behind this procedure is that a moving object of an input image can be predicted in the following image using the input object data and the corresponding object vector. If MPEG-vectors describe object motion, it should be possible to use them for upconversion. This corresponds to the model 2 shown in Fig. 1. A decisive advantage of this method would be that motion estimation in the receiver would not be required (saving chip area for receiver-based motion estimation). Nevertheless, a simple acceptance of the MPEG-vectors is impossible since these vectors can describe different temporal periods.[9] This means that the MPEG-vectors should be adapted concerning their magnitude and and direction in any case.

Since within the MPEG-coding scheme a prediction using several vectors is possible, one vector has to be chosen for the upconversion. This is done according to rules. For example, a zero-vector is chosen for an intra coded block. The interpolation quality by application of MPEG vectors which were transmitted in the MPEG data stream was veryfied in simulation. In Fig. 6, PSNR values of the nonlinear vector-based upconversion method which was applied in this examination is depicted in dependency of different motion vectors for differenttest sequences. Both MPEG-vectors and vectors which were newly computed on the basis of the decoded sequence by a motion estimator were tested. Furthermore the quality of upconversion with analogous transmission using the motion estimator optimized for upconversion is given as reference in each case. These results show clearly that a pure use of MPEG-vectors does not provide a sufficient image quality.

The errors of the MPEG-vectors, i.e. their difference to 'real' motion vectors, is often so strong that even error-correcting interpolation methods have no possibility to compensate the errors of these MPEG-vectors. In

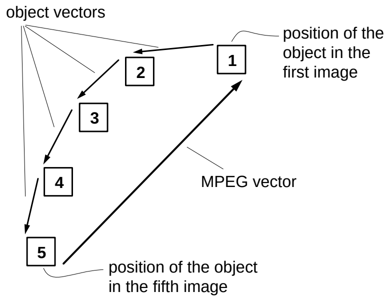


Figure 7: Prediction-based faulty MPEG-vector over several images

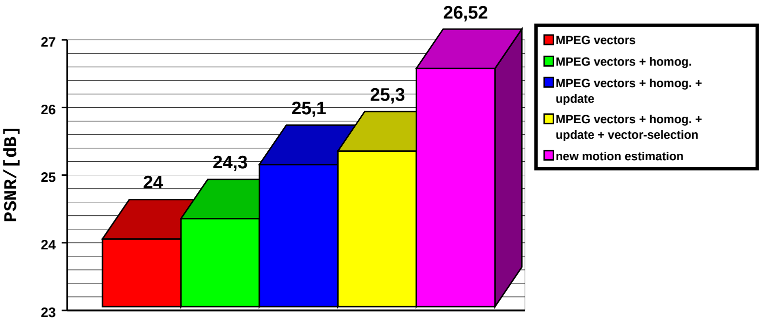


Figure 8: Upconversion quality using modified MPEG-vectors ('BBC-wheel', 5 Mbit/s)

results that: MPEG-vectors *do not* correspond to real motion in a scene as they are only useful to minimize the image difference. MPEG-vectors are *not* suitable as upconversion vectors.

Now since the MPEG-vectors are submitted to the receiver for decoding, the question is whether these vectors can be improved decisively for upconversion without expensive additional expenditure (corresponding to model 3 in Fig. 1). The expense for such a method has to be compared to the expense of a new motion estimation and should be far below this to have an advantage over the new estimation. For this reason in this work the following methods for receiver-based improvement of MPEG-vector-fields have been investigated:

- **Homogenization of the vector field:** Elimination of vector outliers and vector errors at image edges, homogenization of vectors in exposed areas.
- **Modification of vectors by an update strategy:** An MPEG-vector is varied by updates, the newly originated vectors are evaluated and the best vector is chosen. Thus, errors by prediction over several images (see Fig. 7) can sometimes be compensated.
- **Choosing a vector from several MPEG-vector fields:** The vector to be used for upconversion is determined by comparing MPEG-vector fields before and after the actual image.

Fig. 8 shows the obtained upconversion quality vs. the modification method used for the test sequence 'wheel'. As reference, the quality obtained by accepting the pure MPEG-vectors (incl. length adaption) and by using the optimized vectors of a new receiver-based motion estimation are shown as well. These results show that even when using more sophisticated techniques for postprocessing of the MPEG-vector-field the quality of a new estimation is not achieved. Here, the subjective impression of the difference of the particular methods is partly much more as the difference reflected by the PSNR values. Considering the additional expense required for postprocessing (e.g. increased demand of memory when choosing between different MPEG-vector-fields) it seems little reasonable to use the MPEG-vectors for receiver-based upconversion at all, or to use them as a starting-point for a new search.

In general a method using a separate transmitter-based motion estimator optimized for coding and a receiver-based motion estimation method optimized for upconversion achieves the best results. It results that coder vectors and upconversion vectors are not identical and different motion estimators are required for both tasks.

3 NOISE AND ARTIFACT REDUCTION IN MPEG-2 SIGNALS

Noise reduction is an image restoration task that attempts to recover an underlying *perfect* image from a degraded copy. Depending on the application, various types of noise and artifacts can be distinguished.[3] Noise may be generated by signal pick-up in the camera or by film grain. Further noise can be added to the signal by recording or transmission. Channel, recording, film grain and camera (CCD) noise can be modelled as *white* *noise* which is usually of low amplitude. High amplitude noise like *impulse noise* generated through e.g. motor vehicles or satellite transmission requires an individual approach in order to get optimal performance.

'*Blocking*' are block structures which become visible in a MPEG-2 image due to the block-based and motion compensated MPEG-coding scheme. This block structures appear in an image sequence as a '*Dirty Window*'.[2] The boundaries of blocking and dirty windows are small details which are located in the high frequencies.[2] The quantization of the DCT-coefficient in MPEG-2 coding causes overshoot on object contours which is called '*Ringing*'. '*Mosquito effect*' on high frequent image parts is caused due to the different quantization results in successive images and because of the faulty block-based motion estimation on object contours.[2] The human visual system is very sensitive to this details (e.g. abrupt changes, edges) which are located in the high frequencies.

3.1 Noise reduction techniques

A subband-based temporal image restoration algorithm is described in this section to enhance video images corrupted by white additive noise which can reduce the efficiency of e.g. image compression or image analysis. This algorithm is also applicable for reduction of MPEG-artifacts which are temporal non correlated (e.g. Blocking). The goal of the new algorithm is to 'clean' image sequences from noise and artifacts so that the **subjective** quality of transmitted video will be improved in order to get a clear detail and object representation according to the visual noise and artifact perception (Fig. 11).

In general, noise reduction of image data is realized by linear or nonlinear operations on correlated picture elements. This can be achieved by temporal, spatial or hybrid algorithms (Fig. 9). Many spatial noise filter techniques replace each pixel using functions of the pixel's neighborhood. Because image detail and noise usually have common frequency components, they are not separable in the frequency domain. Linear filters therefore tend to blur edges of objects and details. To minimize the conflict between sharpness, smoothing and motion blur, several signal adaptive and object-based noise filter algorithms have been introduced.

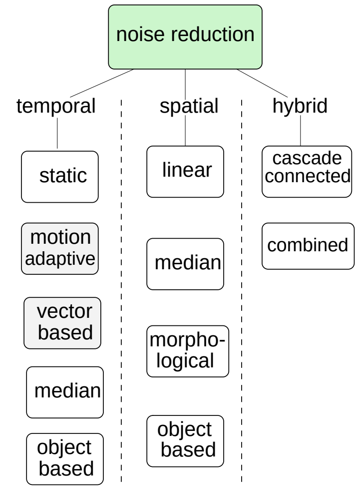


Figure 9: A classification of noise filters

Motion adaptive filters are necessary to prevent smearing of moving objects using temporal recursive filters. Fig. 10 shows the basic concept of a first-order temporal recursive noise filter where MAC is the motion adaptive control unit which detects the amount of motion between the actual input image and the delayed image and translates it monotonously into k. The filter output $g(t)$ is defined as $g(t) = ks(t) + (1-k)s(t-T_p)$, where $s(t)$ is the input luminance signal and T_p is the picture period of the video signal. The amount of (unweighted) noise reduction R in dB can be given[10] as $R = 10\lg\left(\frac{2}{k} - 1\right)$.

Visual noise and artifact perception:[3] A weighting function for image noise describes the perception of noise with respect to its spectral distribution. Fig. 11 illustrates a 2-D weighting function.[11] Here f_r is the cutoff frequency, f^x and f^y are the spatial vertical and horizontal frequencies. According to the scheme of this noise weighting function the perception of the human eye with respect to spatial lower frequencies is more sensitive for noise or artifacts than in high frequency directions. Therefore, for a perception based adapting and optimization of noise filter the reduction process can be splitted in two parts: the low and the high frequency processing.
A subband-based noise and artifact filter: In general the separated high and low frequency processing techniques are oriented to a 2-channel model of the human visual system yielding for the spatial high channel a low temporal resolution and a higher temporal resolution for the low channel.[12] In[3] this general concept is combined with the noise weighting function approach so that effective noise reduction can be achieved meeting the characteristics of the human noise perception. Fig. 12 shows the main blocks of the subband-based noise and artifact filter. Video signal processing in standard interlaced systems has to be performed taking into account the

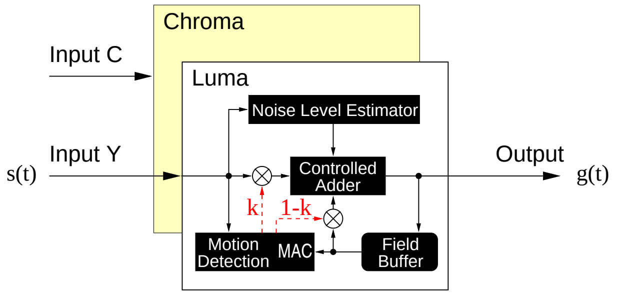


Figure 10: Temporal noise reduction

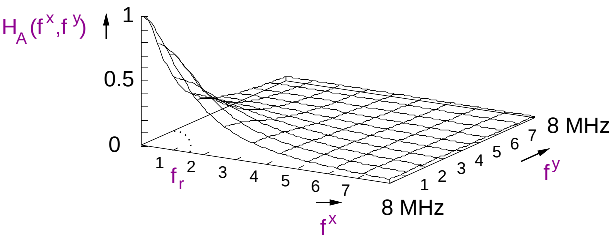


Figure 11: Noise weighting function

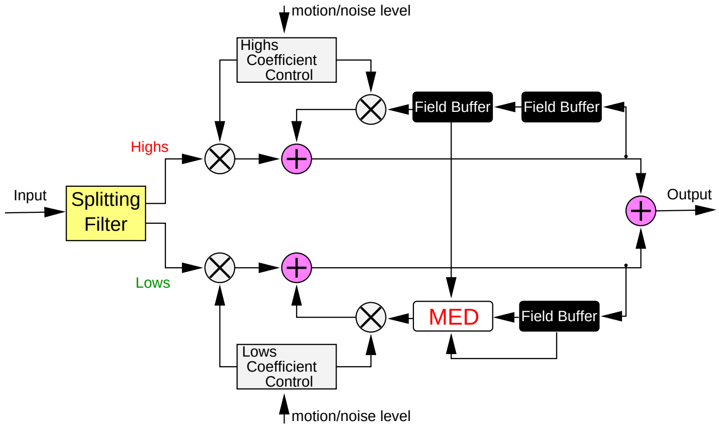


Figure 12: Subband noise processing

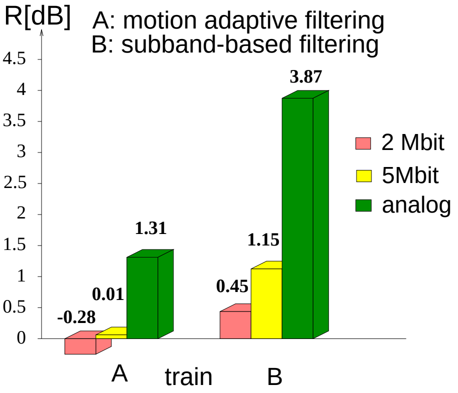


Figure 13: Noisefiltering result in MPEG-2 signals

different field rasters. Since the high channel hold high spatial resolution field processing using the same rasters is proposed. Because of the high temporal resolution in the low channel a first-order recursive noise filter is preferred. Owing to the described weighting noise function different variables k_{highs} and k_{lows} can be separately determined. For the compensation of the interlaced recursive part in the low channel field processing a spatially or interfield dominated median reinterpolation is feasible.

A motion adaptive noise filter averages similar areas in successive images. The proper image information is highly correlated and added linearly, whereas the noise is uncorrelated and fails by adding. However, image correlation breaks down when there is movement in the input sequence. Hence, it is important to use a motion detector to reduce the recursive portion when motion appears. Both, temporal non correlated MPEG-artifacts (e.g. blocking), which are in their natur high frequent and possess low amplitudes, and low frequency white noise, can be reduced using this subbad-based filter as subjective and objective results have shown. This MPEG-artifact and noise reducer can be used as a step before the image analysis methods (motion estimation, object recognition) and before vector-based upconversion in order to increase the performance of these techniques.

3.2 Evaluation of the noise and artifact reducer

The subband-based filter has been tested using the PSNR-method in the way that white noise is added to a 'clean' reference image sequence. The resulting PSNR of the noise reduced image sequence gives the average PSNR over the images of the sequence. In[3] it is shown that in comparison with basic adaptive noise filters the separated highs and lows concept yields significant quality improvement. Even when video sequences are corrupted by strong noise levels the filter stays robust (e.g. by PSNR$\approx$ 26dB, $R \approx 3.5$dB). The subband-based temporal filter has been tested in a digital transmission environment, showing that a good quality improvement of noisy source materials decoded with MPEG-2 decoder is achieved. First an image sequence is corrupted by white noise (e.g. 30dB PSNR), coded and then decoded by the MPEG-2 decoder using a data rate of 5 respectively 2 Mbit. A MPEG-2 decoded sequence contains less original images due to the compression scheme which can lead to artifacts e.g. blocking or Dirty Window. Experimental tests showed that decoded noisy sequences are still noisy so that a subsequent noise reduction process is feasible. The proposed noise reduction scheme delivers fair results as experiments have shown (Fig. 13)

Considering the human visual system which is a nonlinear system a lot of visual phenomena can't be described totally by an objective criterion. Therefore, subjective tests are important for a fair evaluation of enhancement filters. Due to the temporal non correlated feature of MPEG-2 artifacts and because of their natur as high frequent image parts which possess low amplitude the using of the subband-based temporal algorithm is appropriate. Subjective tests of the subband-based algorithm showed that artifact corrupted MPEG-image sequences are improved so that block-flicker due to blocking and dirty windows become significantly reduced.

4 OBJECT RECOGNITION IN MPEG-2 IMAGES

Object-based approaches offer an important feature to support methods of video signal processing (e.g. motion estimation, image encoding).[1,5] For robust object-based techniques robust object recognition methods are needed. In a video scene various types of image changes (e.g. noise, artifacts, illumination changes and overlapping) can appear. In this case the recognition of objects from video signals should stay robust in order to avoid artifacts in object-based techniques.

Object recognition methods could be distinguished into region and contour-oriented methods.[1] The advantage of region-oriented methods, which can be implemented using region growth techniques, is its robustness also in noisy images. Due to the region growth techniques, which require high implementation costs, these methods are not suitable for receiver-based applications. In general contour-oriented methods have low calculation costs. The main disadvantage of contour-oriented methods is their sensitivity to degradation of image quality. In this section a multilevel, contour-oriented and artifact tolerant recognition method is described.[1] Within this method the whole recognition process is devided in simple tasks so that complex arithmetic operations are avoided.

A contour-oriented, artifact-robust object recognizer:
In[1] an object recognition method is described which is carried out by a object isolation and a morphological segmentation of the image, followed by a contour analysis of the objects and an object reconstruction. The goal of this algorithm is to recognize 'significant' and 'not small' objects which are important for further postprocessing of video sequences. This kind of object selection is oriented to the physiological perception of the human eye which tracks such objects due to its increased spatial and temporal resolution by recognizing these objects. An overview of the algorithm's components and the image transformation thus produced is refined in Fig. 14.

Object isolation: The task of object isolation is to find out important potential object regions using a threshold function. The determination of the threshold is done by combination of local (histogram-based) and global (block-based) decision criteria. In this way the threshold is adapted to the contents of each image in the sequence. Thus a dynamic adaption of the threshold value is achieved taking into account illumination- and object changes during a video sequence. The calculating function outstands for its interferences invariance.[1]

Morphological detection of contour points: Using a newly defined rule for morphological erosion[1] and a fixed 2x2 pel structured element the binary image is first being eroded depending on the pixel constellation in the structured element (Fig. 16). Then the result is subtracted from the binary image, thus producing a contour point image (Fig. 15[1]). To achieve high performance of the following object recognition steps the accuracy of edge position, the robustness against noise and the detection of one-pixel-wide edges are essential criteria. These goals were taken into account when the new morphological erosion and the structured element was designed.

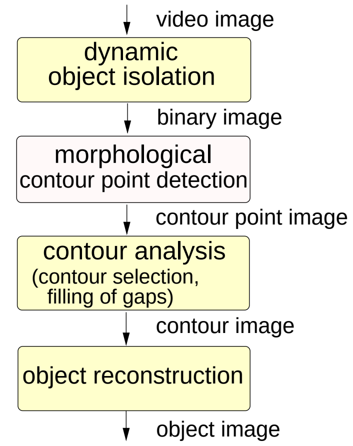


Figure 14: Multilevel contour-oriented object reconition

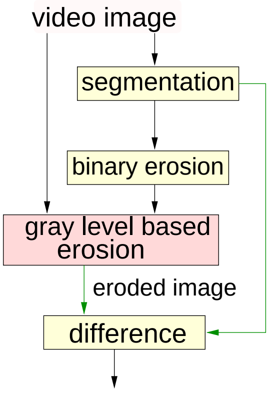


Figure 15: Morphological edge detection

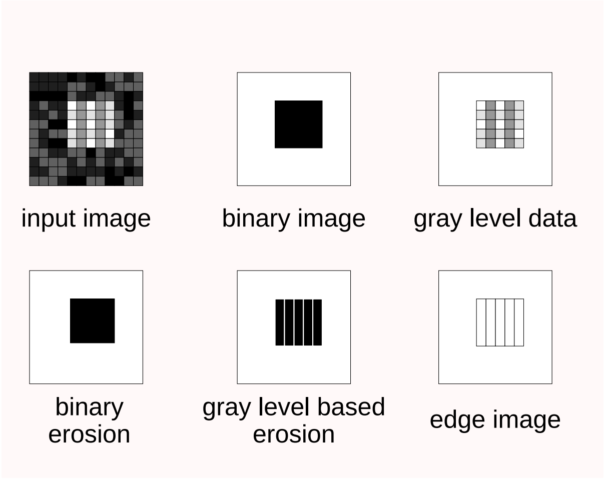


Figure 16: A new graylevel erosion

Contour analysis: The previous image transformation deliver independent contour elements which are not spatial correlated. To become global object information (object contour) discret chains of the contour points should be generated. Within this processing step contour which are small or not significant are eliminated (Fig. 17e). This is due to the fact that small (moving) objects are not important for the perception of an image. In *an* edge detection algorithm different artifacts *can* arise (noise corrupted edges, faulty detection (gaps)). The contour tracking works error tolerant so that small or wrong detected contours, which are not significant for further postprocessing, are eliminated.

Object reconstruction: In general, the contour image, only characterized by contour points and their spatial relationship, is not sufficient for a high quality object-based image processing, which based on the data of the position of the object points. Therefore an object image, whose discret objects correspond to the structures included in the input image(see Fig. 17a and f, is reconstructed by simple rules from the contour image.

Robustness of the object recognizer: The imagewise isolation of potential object regions was shown as very noise-robust by various sequence simulations. The developed morphological contour point detector has been compared to various methods (gradient- and morphological-based). It has shown noise robustness, accuracy of points positions and it yields gaps free edges (Fig. 17d). In particular the contour point detector outstands for very low calculation costs. The object reconizer was verified in many simulation tests showing that it stay robust, even on very low-bit MPEG-2 decoded images (2Mbit/s)(Fig. 17h and i). The robustness of the method can also be demonstrated on heavy (white and impulsive) noisy image sequences (see Fig. 17b and g).

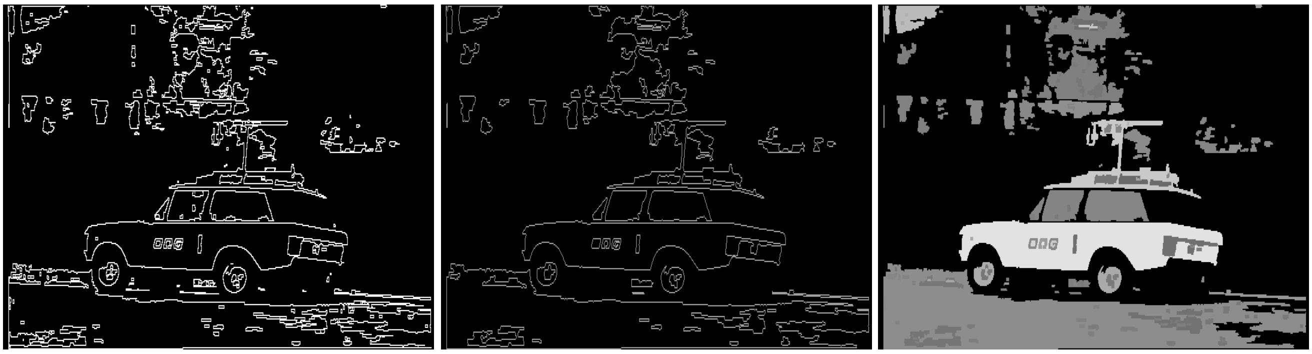
5 DISCUSSION AND CONCLUSION

In this paper the applicability and the robustness of developed postprocessing modules in a digital transmission environment has been shown. Several models for receiver-based upconversion from 50 Hz interlace to 100 Hz interlace of MPEG-transmitted images were examined. An analysis of the existing upconversion algorithms proves, that vector-based methods have significant advantages by comparison with static algorithms, also with MPEG-transmitted image data. Even with MPEG-transmitted image signals a vector-based nonlinear upconversion with error-compensating median masks could obtain the significantly best interpolation results. Here, the advantage of this method is based in artifact reduction, provided by the error-compensating median masks in the case of faulty vectors. They tend to suppress uncorrelated faulty shifted image parts, which is perceived much less disturbing

(a) 'BBC-car'

(b) noisy image (30dB and 1% Impulsive noise)

(c) potential object regions



(d) edge image

(e) contour image

(f) recognized objects

(g) objects of the noisy image

(h) objects of the MPEG-image, 5Mbit

(i) objects of the MPEG-image, 2Mbit

Figure 17: Simulation results of the multilevel object recognition

than incorrect shifting these image areas.

This paper has also presented a subband-based algorithm for image restoration adapted to the requirements of the human visual system, e.g. human noise and artifact perception characteristics. Objective evaluation of the subband-based algorithm and the comparison with known temporal noise filters have shown a significant quality improvement also in a digital transmission environment (MPEG-2), with a good quality improvement even for noisy source materials. Using a subband-based noise filter temporal non correlated MPEG-artifacts can also significantly be reduced.

Using the described subband-based nonlinear MPEG-artifact and noise reduction, and the vector-based nonlinear upconversion a postprocessing system for high quality demands can be achieved. Object-based approaches provide an important basis to support methods of high quality video signal processing. Therefore a morphological, contour-based object recognition method has been presented showing that even in strongly corrupted MPEG-2 images the method stays robust. The described MPEG-artifact and noise reducer can be used as a step before the image analysis methods (motion estimation, object recognition) and before vector-based upconversion in order to increase the performance of these techniques.

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6 REFERENCES

[1] Amer, A.: *Ein mehrstufiges Verfahren zur robusten Objekterkennung in Videosequenzen*, to appear in the 9^{th} Aachen Symposium 'Signaltheorie', Aachen (Germany): March 1997 (in German)

[2] Amer, A.; Blume, H.: *Nachverarbeitung MPEG-2 decodierter Bilder*, ITG-Workshop: Multimedilae Anwendungen und Endgeräte, Darmstadt (Germany): October 1996 (in German)

[3] Amer, A.; Schröder, H.: *A New Video Noise Reduction Algorithm Using Spatial Subbands*, Third IEEE International Conference on Electronics, Circuits, and Systems, Rodos (Greece): October 1996

[4] Blume, H.: *Vector-Based Nonlinaer Upconversion Applying Center Weighted Medians*, IS&T/SPIE Symposium on Electronic Imaging, Nonlinear Image Processing VII, San Jose (USA): 28.1.-2.2.1996

[5] Blume, H.; Amer, A.: *Parallel Predictive Motion Estimation Using Object Recognition Methods*, European Workshop and Exhipition on Image Format Conversion and Transcoding, Berlin (Germany): March 1995

[6] Blume, H.; Schwoerer, L.; Zygis, K.: *Subband Based Upconversion Using Complementary Median Filters*, 7th Inter. Workshop on HDTV and Beyond, Torino (Italy): 1994

[7] Botteck, M.: *Digital Signal Processing with separated Lows and Highs for TV applications*, 26th Annual SMPTE Advanced Television and Electronic Imaging Conference, San Francisco (USA): February 1992

[8] de Haan, G. et al: *IC for Motion Compensated 100 Hz TV with smooth Movie Motion Mode*, Proceedings of the ICCE, Chicago (USA): 7.-9. 6. 1995

[9] Ely, S.R.: *MPEG video coding: a basic tutorial introduction*, BBC Research Department Report: 1996/3

[10] Drewery, J.O.; Storey, R.; Tanton, N.E.: *Video Noise Reduction*, BBC Research Department Report: 1984/7

[11] Fujio, T.: *A Universal Weighted Power Function of Television noise and its Application to High-Definition TV System Design*, IEEE Trans. on Broadc., Vol. 26, No. 2: 1980

[12] Schröder, H.: *Image Processing for TV-Receiver Applications*, IEE International Conference on Image Processing and its Applications, Maastricht (Netherlands): April 1992

[13] Schröder, H.; Blume, H.: *Image Format Conversion - from Signal Theory to Applications*, European Workshop and Exhibition on Image Format Conversion and Transcoding, Berlin (Germany): 22.-23. 3. 1995