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An adaptive fuzzy filter for coding artifacts removal in video and image

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Abstract: This paper proposes a new adaptive post-filtering algorithm to remove coding artifacts in block-based video coder. The proposed method concentrates on blocking and ringing artifacts removal. For de-blocking, the blocking strength is identified to determine the filtering range, and the maximum quantization parameter of the image is used to adapt the 1D fuzzy filter. For de-ringing, besides the edge detection, a complementary ringing detection method is proposed to locate the neglected ringing blocks, and the gradient threshold is adopted to adjust the parameter of 2D fuzzy filter. Experiments are performed on the MPEG-4 sequences. Compared with other methods, the proposed one achieves better detail preservation and artifacts removal performance with lower computational cost.

Key words: Adaptive fuzzy filter, Blocking artifacts, Ringing artifacts, De-blocking, De-ringing
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INTRODUCTION

Nowadays, with the development of signal processing, compression technology has been widely applied in various applications, including digital cameras, DVD, and broadcast. However, these applications are all bothered by an annoying problem, i.e., coding artifacts, which are caused by the quantization and coefficient truncation process. The higher compression ratio is, the more disturbing artifacts there are.

For most image and video compression standards, such as JPEG, MPEG, H.261, H.263, and H.264, using block-based processing, the most obvious coding artifacts are the blocking and ringing artifacts. The blocking artifacts appear as grid noise along the block boundaries in smooth areas, which are caused by the independent encoding of each block without considering the correlation between adjacent blocks. And the ringing artifacts show spurious oscillations in the vicinity of major edges, which are introduced by abrupt truncation of high frequency components.

Many post-processing methods have been proposed to reduce these coding artifacts, including partial differential equations (PDEs) (Bourdon *et al*., 2004; Yao *et al*., 2004), maximum a posteriori (MAP) (Yang *et al*., 2000), projections onto convex sets (POCS) (Gan *et al*., 2003; Zou and Yan, 2005), wavelet transform coefficients analysis (Wu *et al*., 2001; Liew and Yan, 2004), and spatial post-filter. The PDE and MAP methods need prior information of the original images to determine the parameters, which would burden the video/image encoder, and is unacceptable for industry. The POCS and wavelet transform coefficients analysis methods can work with no reference, but their computational complexity is too high for real-time applications. In contrast, spatial post-filter is much simpler and more practical.

One popular spatial post-filter for artifacts removal is introduced in the appendix of MPEG-4 (ISO/IEC 14496-2, 2001). It first adopts the de-blocking method proposed by Kim *et al*.(1999), which classifies the image into smooth mode and default mode according to pixel behaviors around the block boundaries and performs different strength filtering on them. And then, a de-ringing method based on simple average filter follows. This algorithm does a good job in blocking judgment, especially in the smooth region. But when blocking artifacts are serious, its performance drops dramatically. On the other hand, for most of the time its de-ringing effect is unsatisfactory.

An improved coding artifacts removal method was put forward by Kirenko (2006). It also detects possible locations of blocking and ringing artifacts by analyzing local spatial activities of luminance and chrominance components, and then three mode filters are applied respectively depending on the outcome of the analysis. However, when blocking artifacts also exist in chrominance components, they may be misjudged as the object edge and cannot be removed as a result.

Nie *et al.*(2005) presented a new method using fuzzy filtering to remove the coding artifacts in compressed video. For de-blocking, the block edge strength is detected, and a 1D fuzzy filter adjusts its window size and filtering range according to it. For de-ringing, 8×8 blocks are finely classified into four categories and a 2D fuzzy filter with adaptive spread parameter is applied on them. This method involves a promising filter, i.e., fuzzy filter, but its artifact judgment method is not accurate enough. When blocking artifacts or ringing artifacts get serious, the corresponding judgment conditions become invalid.

In this paper, we propose a new adaptive post-filtering algorithm, as shown in Fig.1, to remove the coding artifacts. It is based on the fuzzy ordering theory (Nie and Barner, 2003; 2006; Nie *et al.*, 2005) and has superior performance in artifacts removal and detail preservation. The remainder of this paper is organized as follows. First, the proposed de-blocking and de-ringing algorithm are respectively described in detail. Then, the experiment and comparison results are presented. Finally, the conclusions and future research direction are given.

DE-BLOCKING

The proposed de-blocking algorithm consists of blocking artifact detection and de-blocking filtering. The flowchart of de-blocking algorithm is shown in Fig.2. It is applied on all the 8×8 block boundaries first along the horizontal edges followed by the vertical edges. Luminance component and chrominance component are dealt with in the same way. Here, we take the vertical block artifacts removal as an example.

Blocking artifact detection

The first step of the proposed algorithm is detecting the blocking artifacts. Since the detected block strength will indicate the existence of the artifacts and their influence, the detection accuracy is very important. And to avoid the blur in the texture and edge areas, the detection method should be able to distinguish blocking artifacts from object edges.

Fig.3 shows the block boundary of interest in blocking artifact detection. In each row, there is a vector $\boldsymbol{v}=[v_0, v_1, ..., v_9]$. The difference between each

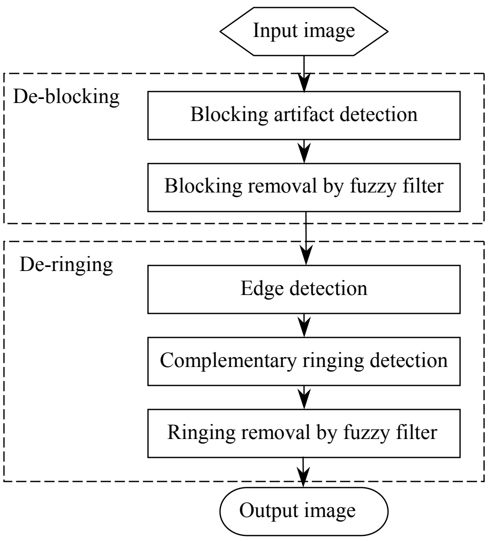


Fig.1 The general flow of the proposed coding artifacts removal algorithm

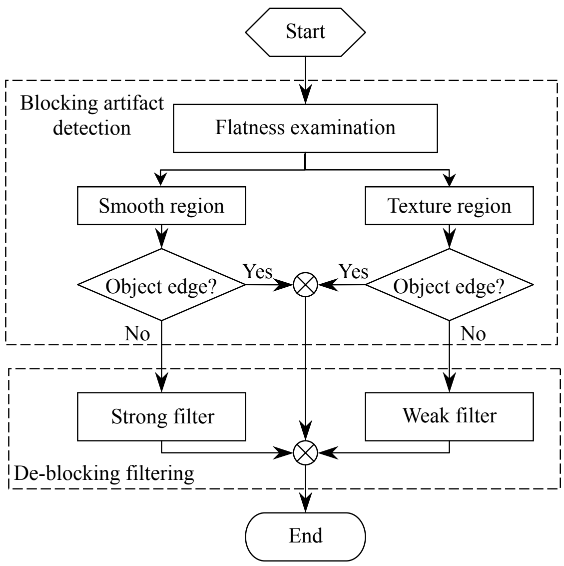


Fig.2 The flowchart of the proposed de-blocking algorithm

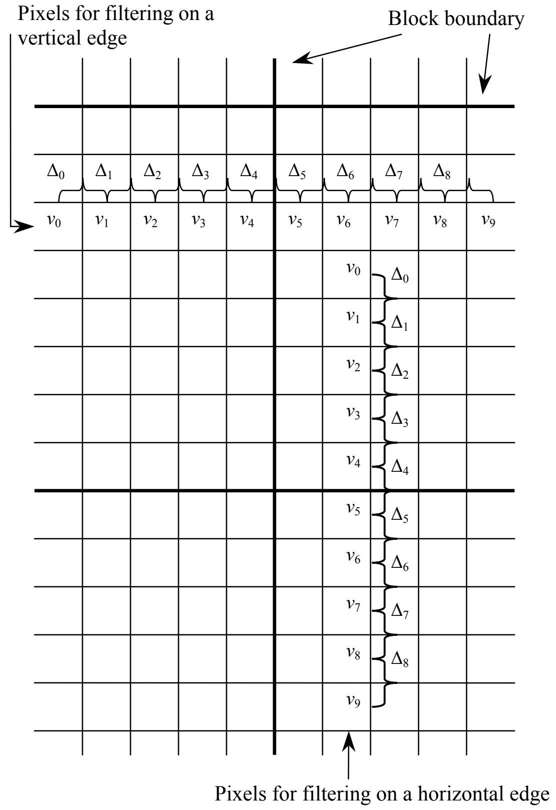


Fig.3 Boundary area around the block of interest in blocking artifact detection

pair of adjacent pixels in the vector is calculated by

$$\Delta_i = v_i - v_{i+1}, \quad i = 0, 1, ..., 8. \tag{1}$$

And according to the flatness measure rule in MPEG-4 (ISO/IEC 14496-2, 2001), the row can be classified into smooth area and texture area:

$$\begin{cases} \phi(\Delta_i) = \begin{cases} 1, & |\Delta_i| \le T_1, \\ 0, & |\Delta_i| > T_1, \end{cases} \\ F(\boldsymbol{v}) = \sum_{i=0}^{8} \phi(\Delta_i), \\ Area(\boldsymbol{v}) = \begin{cases} 1, F(\boldsymbol{v}) \ge T_2 \Rightarrow SmoothArea, \\ 0, F(\boldsymbol{v}) < T_2 \Rightarrow TextureArea, \end{cases} \end{cases} \tag{2}$$

where, T_1=2, T_2=6.

In smooth area, $Area(\boldsymbol{v})$=1, the blocking artifact is judged by

$$block\_artifact = \begin{cases} 1, & |\max(\boldsymbol{v}) - \min(\boldsymbol{v})| < 2 \cdot QP, \\ 0, & |\max(\boldsymbol{v}) - \min(\boldsymbol{v})| \ge 2 \cdot QP, \end{cases} \tag{3}$$

where, *block_artifact*=1 denotes a blocking artifact is detected between v_4 and v_5 in the current row, and *block_artifact*=0 denotes an object edge exists and no further process is needed. The threshold *QP* is the quantization parameter of the block which pixel v_5 belongs to. In smooth area, the detected artifacts are more obvious, which are considered as strong blocking artifacts. Then the filtering range which will be adopted in the next step is set from v_1 to v_8.

In texture area, $Area(\boldsymbol{v})$=0, object edges make a great impact on the artifact judgment, so another accurate comparison method based on the magnitude of abrupt change across block boundary is applied:

$$\max(\Delta_i) < \Delta_4, i = 0, 1, 2, 3, \tag{4}$$

$$\max(\Delta_i) < \Delta_4, i = 5, 6, 7, 8. \tag{5}$$

And the blocking artifact is detected:

$$block\_artifact = \begin{cases} 1, & (4) \,||\, (5), \\ 0, & \text{otherwise}, \end{cases} \tag{6}$$

where, the *block_artifact* has the same meaning with Eq.(3). Since this is in texture area, the detected artifact is considered as a weak blocking artifact. The filtering range is set from v_3 to v_5 or from v_4 to v_6 according to whether Eq.(4) or Eq.(5) holds.

De-blocking filtering

After blocking artifacts detection, a 1D fuzzy filer is applied along the marked filtering range in each row to remove blocking artifacts. The fuzzy filter based on fuzzy transformation theory is defined as (Nie *et al.*, 2005):

$$\begin{cases} d(x+i, y) = |v_B(x+i, y) - v_B(x, y)|, \\ v_B(x, y) = \sum_{i=-N/2}^{N/2} v(x+i, y) w_i \Big/ \sum_{i=-N/2}^{N/2} w_i \\ = \sum_{i=-N/2}^{N/2} v(x+i, y) \mu[d(x+i, y)] \Big/ \sum_{i=-N/2}^{N/2} \mu[d(x+i, y)], \end{cases} \tag{7}$$

where N is the window size, N=9, $v(x,y)$ is the pixel value of decoded image in location (x,y), $v_B(x,y)$ is the de-blocking result of pixel (x,y). And $\mu(x)=\exp[-x^2/(2\sigma^2)]$ is a Gaussian function to describe the relationship between pixels by their distance. To reduce the computational complexity, a piecewise linear function $\mu_L(x)$ is used (Nie *et al.*, 2005) to approximate the Gaussian function $\mu(x)$:

$$\mu_{\mathrm{L}}(x)=\begin{cases}1, & 0\le x\le(2-\mathrm{e}^{0.5})\sigma,\\ \mathrm{e}^{-0.5}(2-\sigma^{-1}x), & (2-\mathrm{e}^{0.5})\sigma<x<2\sigma,\\ 0, & x\ge 2\sigma,\end{cases}\quad(8)$$

so that $w_i=\mu_{\mathrm{L}}(|v(x,y)-v(x+i,y)|)$. Here, σ is the spread parameter. The larger it is, the stronger is the smoothing effect. So we adapt this parameter to the block quantization scale which determines the level of blocking. And according to the characteristics of Gaussian function, σ is set to the maximum block quantization parameter $QP_{\max}$ in the image.

DE-RINGING

In our proposed method, ringing artifact removal follows the de-blocking algorithm, which also can be used independently. The de-ringing algorithm is composed of three parts: edge detection, complementary ringing detection and de-ringing filtering. Fig.4 shows the flowchart of the proposed de-ringing algorithm.

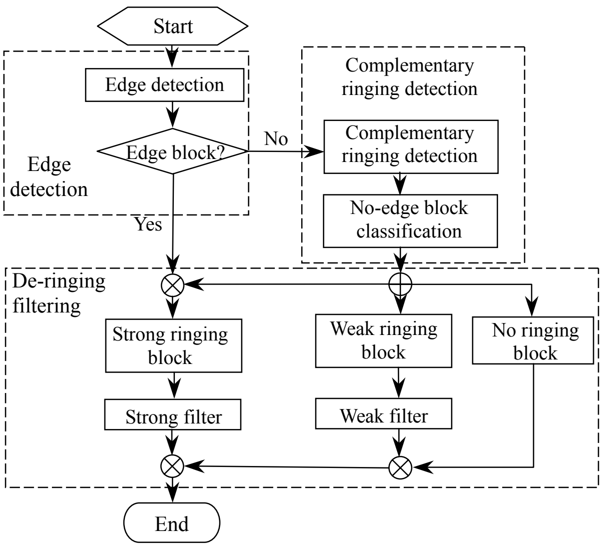


Fig.4 The flowchart of the proposed de-ringing algorithm

Edge detection

Edge detection is the first step of de-ringing algorithm. Because ringing artifacts always arise along the object edges, a precise edge detection is necessary. Here, the fuzzy edge detection method proposed by Kuo *et al.*(1997) is adopted.

First, a difference histogram H of the image is built based on the statistics of the maximum difference in a 3×3 window around each pixel.

$$d(x,y)=\max|v_{\mathrm{B}}(x,y)-v_{\mathrm{B}}(x+i,y+j)|,\quad i=-1,0,1;\ j=-1,0,1.\quad(9)$$

where, $v_{\mathrm{B}}(x,y)$ is the pixel value of de-blocking image in location (x,y). So $H(i)$ denotes the number of pixels whose maximum difference in gray-level value is i. According to this statistics, the summation T of maximum differences $d(x,y)$ for all pixels is also computed:

$$T=\sum_{y=0}^{H}\sum_{x=0}^{W}d(x,y),\quad(10)$$

where W is the image width, and H is the image height. Also, the total pixel number N is recorded:

$$N=W\times H.\quad(11)$$

Then, the following rule works on the difference histogram. The gray value K that satisfies this formula is set to the gradient threshold GT:

$$\frac{1}{T}\sum_{i=0}^{K}i\cdot H(i)\le\frac{1}{N}\sum_{i=0}^{K}H(i)<\frac{1}{T}\sum_{i=0}^{K+1}i\cdot H(i).\quad(12)$$

And depending on this gradient threshold GT, Sobel operators are performed.

$$\boldsymbol{G}_x=\begin{bmatrix}1&2&1\\0&0&0\\-1&-2&-1\end{bmatrix},\ \boldsymbol{G}_y=\begin{bmatrix}1&0&-1\\2&0&-2\\1&0&-1\end{bmatrix}.\quad(13)$$

The edge pixel map is

$$edge(x,y)=\begin{cases}1, & sobel(x,y)\ge GT,\\ 0, & sobel(x,y)<GT.\end{cases}\quad(14)$$

These detected edge pixels are strong and clear. No matter what they are (real object edges or ringing artifacts), the block which contains edge pixels is regarded as a strong ringing block.

$$ring\_artifact=\begin{cases}2, & \{edge(x,y),(x,y)\in Block\},\\ 0, & \text{otherwise},\end{cases}\quad(15)$$

where, *ring_artifact*=2 denotes a strong ringing artifact is detected in the current block, and *ring_artifact*=0 denotes no ringing artifact exists and no further process is needed.

Complementary ringing detection

Although edge detection can locate most strong ringing artifacts, in the area where ringing artifacts are serious, the edge detection may miss the edges masked by artifacts. Moreover, due to motion estimation, the no-edge blocks next to the edge blocks may also contain ringing artifacts. As a result, we apply complementary ringing detection to recover them.

Complementary ringing detection works on the 8-adjacent no-edge blocks of edge blocks (Fig.5). It calculates the variance *Var*(*x*,*y*) in a 3×3 window around each pixel in the detected block:

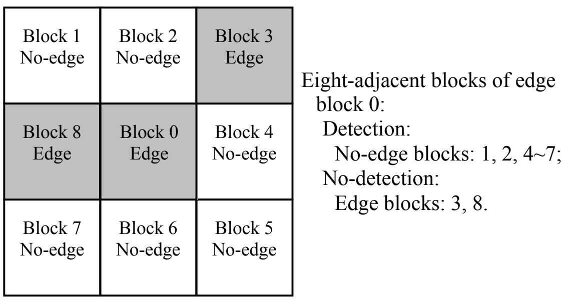


Fig.5 The 8-adjacent blocks of interest in complementary ringing detection

$$\begin{cases} \bar{v}_\mathrm{B}(x,y)=\dfrac{1}{9}\sum_{j=-1}^{1}\sum_{i=-1}^{1}v_\mathrm{B}(x+i,y+j), \\ Var(x,y)=\dfrac{1}{9}\sum_{j=-1}^{1}\sum_{i=-1}^{1}v_\mathrm{B}(x+i,y+j)-\bar{v}_\mathrm{B}(x,y). \end{cases} \tag{16}$$

And choose the maximum one as the variance of this block

$$STD_\mathrm{B}=\max\{STD(x,y),(x,y)\in Block\}. \tag{17}$$

Then, it compares STD_B with a set of predetermined threshold to redefine $ring\_artifact$ of this block:

$$ring\_artifact=\begin{cases} 2, & HT\le STD_\mathrm{B}, \\ 1, & LT\le STD_\mathrm{B}<HT, \\ 0, & STD_\mathrm{B}<LT, \end{cases} \tag{18}$$

where *ring_artifact*=2 and *ring_artifact*=0 have the same meanings with Eq.(15). And *ring_artifact*=1 denotes a weak ringing artifact is detected in the current block, and this block is regarded as a weak ringing blocks. *HT* is the upper threshold, *LT* is the lower threshold. For the gradient threshold of Sobel, *GT* presents the characteristics of the image, with which the thresholds *HT*, *LT* are associated. By experiment, the relationships are defined as:

$$\begin{cases} HT=(GT/8)^2/\sqrt{2}, \\ LT=\max(GT/16, HT-100). \end{cases} \tag{19}$$

Now, all the ringing blocks have been detected.

De-ringing filtering

According to the two-step detection, a 2D adaptive fuzzy filter is adopted on the ringing blocks, excluding the edge pixels, to remove ringing artifacts:

$$\begin{cases} v_\mathrm{R}(x,y)=\dfrac{\sum_{j=-N/2}^{N/2}\sum_{i=-N/2}^{N/2}v_\mathrm{B}(x+i,y+j)\mu_\mathrm{L}[d(x+i,y+j)]}{\sum_{j=-N/2}^{N/2}\sum_{i=-N/2}^{N/2}\mu_\mathrm{L}[d(x+i,y+j)]}, \\ d(x+i,y+j)=|v_\mathrm{B}(x+i,y+j)-v_\mathrm{B}(x,y)|, \end{cases} \tag{20}$$

where N is the window size, N=9. $\mu_\mathrm{L}(x)$ is defined in Eq.(8), $v_\mathrm{B}(x,y)$ is the pixel value of de-blocking image in location (x,y), and $v_\mathrm{R}(x,y)$ is the de-ringing result of pixel (x,y) in de-blocking image.

At the same time, with different values of *ring_artifact* in the ringing blocks, there are two definitions of σ. They are both adapted to the gradient threshold *GT* to keep image characters:

$$\sigma=\begin{cases} GT/8, & ring\_artifact=2, \\ GT/16, & ring\_artifact=1. \end{cases} \tag{21}$$

This filtering is also done on the Cr, Cb image in the corresponding blocks.

EXPERIMENT RESULTS

Simulation is performed by using the Xvid MPEG-4 1.0.1 coder for low bit-rate DCT-based video compression. The prediction mode with 16×16 macro-block motion vectors and regular motion compensation are turned on, and the motion search range is [−32, 31.5]. The H.263 quantization method is adopted, and fixed quantization parameters (10, 15, and 20) are used for all test sequences. These sequences with CIF and QCIF resolutions have a chroma format of 4:2:0 and frame frequency of 25 Hz. Each test sequence has 100 frames, and only the first frame is coded as an intra (I) frame, others are coded as predictive (P) frames.

In order to evaluate the performance of the proposed coding artifacts removal method, three existing methods are also realized for comparison: the MPEG-4 filter described in MPEG-4 standard (ISO/IEC 14496-2, 2001), the CL Analysis proposed by Kirenko (2006), and the Fuzzy Filter mentioned by Nie *et al.*(2005).

The block impairment metric (BIM) (Wu and Yuen, 1997) and the PSNR are adopted as objective comparison standard. Comparisons of their results are shown in Table 1 and Table 2, respectively. In BIM comparison, MPEG-4 filter has the best results. The BIM value of the proposed method approached farthest from that of MPEG-4 filter. And the worse the blocking artifacts are, the larger gain they have. In PSNR comparison, the proposed method is the best one. As the weak de-ringing algorithm, MPEG-4 filter falls behind (Fig.8).

On the other hand, the perceptual quality of the artifact removed video is used for subjective judgment. Fig.6 and Fig.7 show the processed results of sequences which are mainly disturbed by blocking artifacts. The CL analysis method and fuzzy method misjudge the strength of blocking artifacts and cannot remove them drastically. The MPEG-4 filter does well in most cases, but when blocking artifact is serious, the MPEG-4 method also brings some misjudgments (see Fig.7). On the contrary, our proposed method does not have these problems. It performs well in different conditions and does not blur the object edges. At the same time, Fig.8 shows the processed results of sequences which are mainly disturbed by the ringing artifacts. The proposed method outperforms other ones, too.

Table 1 BIM improvements of images processed by various postprocessing algorithms*

Sequence	QP	Decoded BIM (dB)	Postprocessed BIM (dB)			
			MPEG-4	CL	Fuzzy	Proposed
Container	10	1.514	1.235	0.746	1.296	1.282
	15	1.924	1.362	0.812	1.497	1.485
	20	2.364	1.401	0.857	1.644	1.636
Hall	10	1.831	1.349	0.864	1.337	1.325
	15	2.401	1.467	0.962	1.592	1.577
	20	3.006	1.657	1.063	1.875	1.853

* Size: QCIF

Table 2 PSNR improvements of images processed by various postprocessing algorithms

Sequence	QP	Decoded PSNR (dB)	Postprocessed PSNR (dB)			
			MPEG-4	CL	Fuzzy	Proposed
Container*	10	33.52	33.72	32.18	32.25	33.79
	15	30.93	30.99	30.29	30.53	31.17
	20	29.13	29.24	28.84	28.96	29.34
Hall*	10	33.89	34.15	33.09	32.74	34.21
	15	31.46	31.53	31.21	31.11	31.67
	20	29.72	29.95	29.81	29.78	30.01
Mobile**	10	30.16	30.39	29.16	29.42	30.41
	15	28.09	28.12	27.35	27.73	28.29
	20	26.21	26.27	25.79	26.08	26.23

Size: *: QCIF; **: CIF

The proposed method is performed on a Pentium IV 2.4 GHz Machine with 256 MB RAM and its processing speed is fast, especially in the de-blocking part. For a QCIF video, it is 0.033 s/frame (only de-blocking, 0.006 s/frame). And for a CIF video it is 0.15 s/frame (only de-blocking, 0.022 s/frame). So, the de-blocking algorithm of this method can work in real time environments, while the de-ringing part needs speedup in the future.

CONCLUSION AND FUTURE WORK

In this paper, we proposed a new adaptive post-filtering algorithm to remove coding artifacts. It detects the possible locations of artifacts and adapts the filtering strength to the detected artifact level. Then, a fuzzy filter based on detection results is used. Experiment results showed that this method outperforms the others in both objective and subjective comparisons. Moreover, its processing speed is fast, especially the de-blocking part, which can satisfy the real-time application requirements. In the future, we will mainly concentrate on the speedup and improvement of de-ringing algorithm.

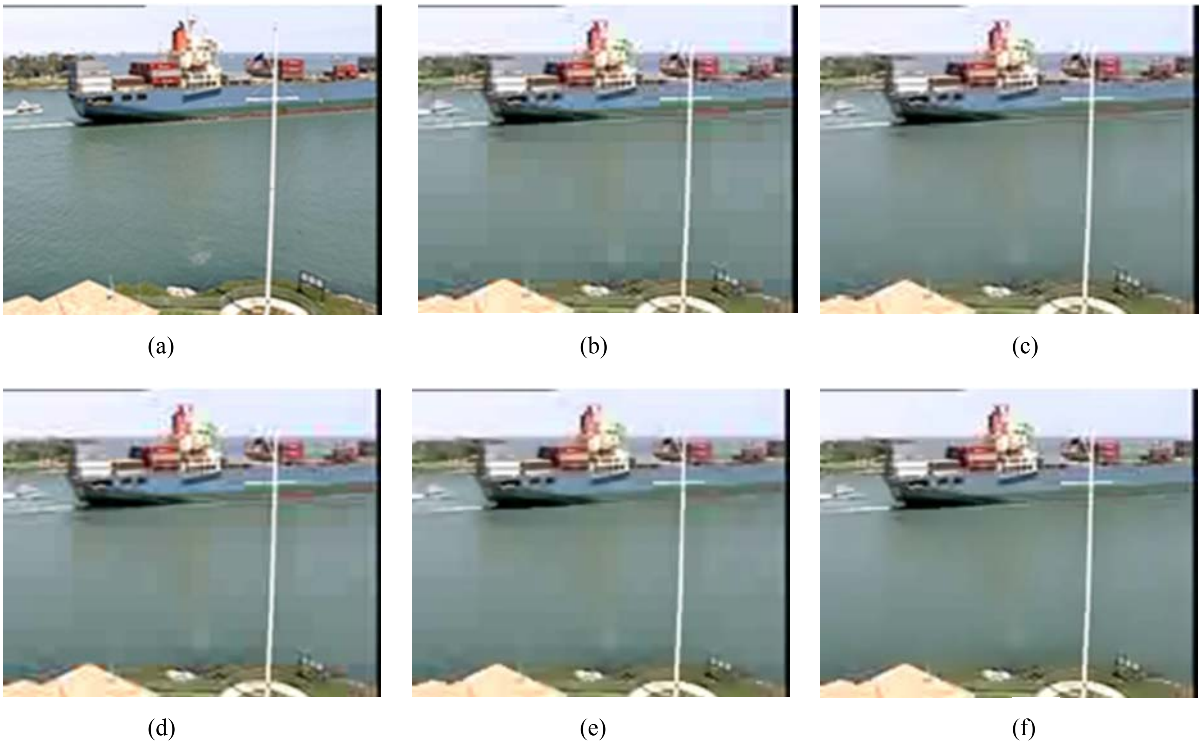


Fig.6 Artifacts removal results for the Container Ship sequence (QCIF, *QP*=20). (a) Original image; (b) No filtering; (c) MPEG-4; (d) CL Analysis; (e) Fuzzy; (f) Our proposed method

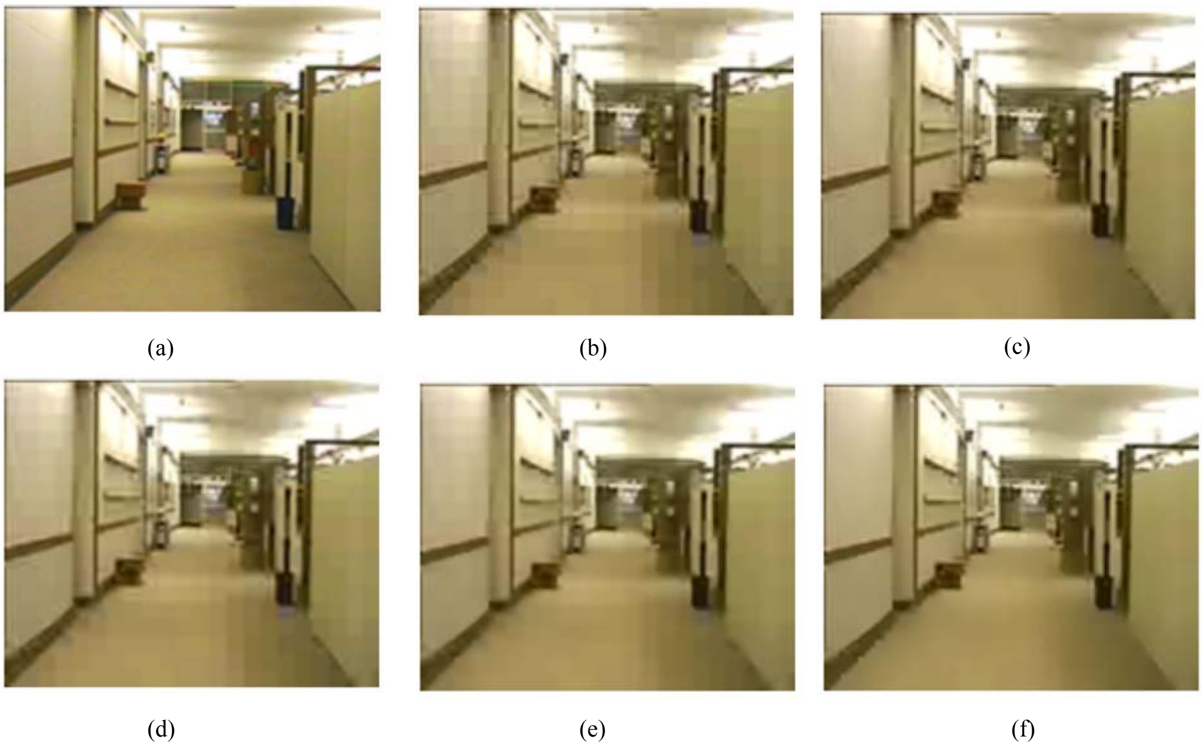
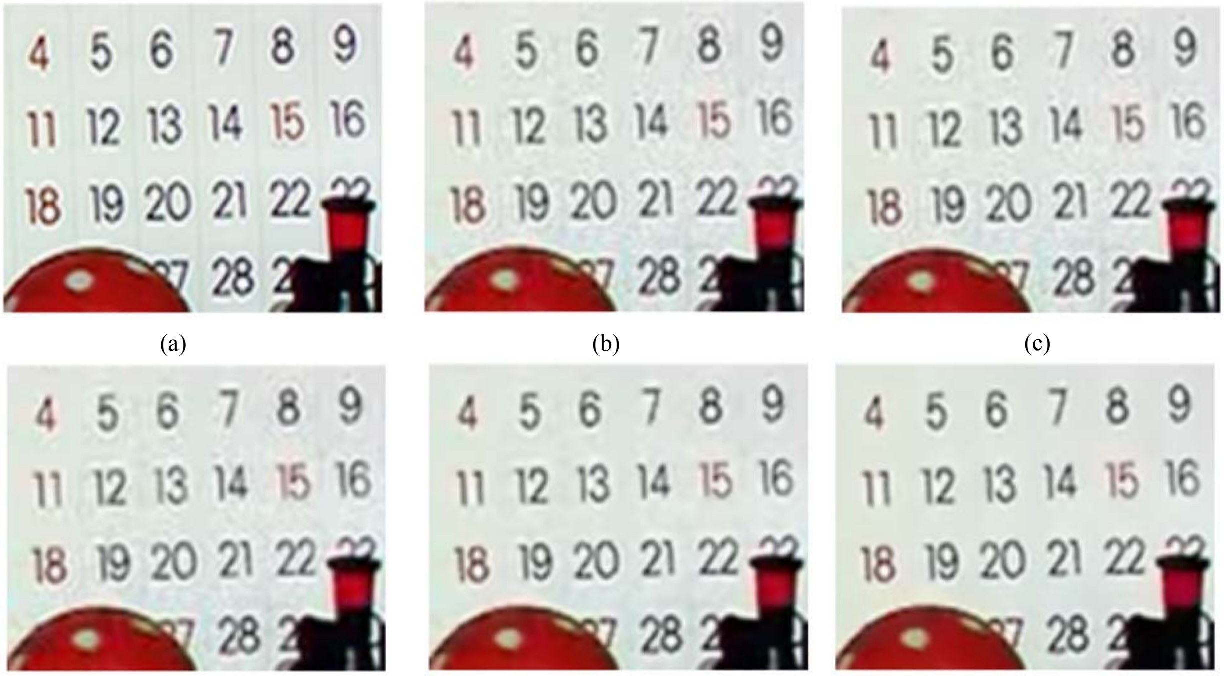


Fig.7 Artifacts removal results for the Hall sequence (QCIF, *QP*=20). (a) Original image; (b) No filtering; (c) MPEG-4; (d) CL Analysis; (e) Fuzzy; (f) Our proposed method



(a) (b) (c) (d) (e) (f)

Fig.8 Artifacts removal results for part of the Mobile sequence (CIF, *QP*=20). (a) Original image; (b) No filtering; (c) MPEG-4; (d) CL Analysis; (e) Fuzzy; (f) Our proposed method

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