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Video Coding Experts Group (Question 15)

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Title: A poster filter to ameliorate blocking artifacts and ringing effects

Purpose: Proposal

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1. Introduction

A 2D poster filtering approach using a pixel based regularization theory is proposed and applied to TMN8 in order to simultaneously ameliorate the blocking artifacts and ringing effects. Since the compressed images have annoying high frequency components, such as, the blocking artifacts and ringing effects which are caused by quantization process, a restoration method to adaptively control the relative contribution of the low and high frequency components is expected. The regularization theory has been utilized to resolve the above problem. In order to reduce the computational complexity in regularization approach, a pixel-based method is defined and applied. In this proposal, a new function to incorporate the four directional smoothness into the solution and to be minimized with respect to the original pixel is proposed, and the regularization parameters to control the fidelity to the data and the smoothness are calculated from the available overhead information in decoder. No information is, therefore, necessary to determine the parameters.

2.The Proposed Pixel Based Regularization Approach

In this proposal, a new function to define the relative contribution of the fidelity of a pixel in compressed image to the pixel in the original image and the smoothness between the original pixel and its four neighbors is defined for reducing the blocking and ringing effects simultaneously. The regularization parameters to define the degree of the smoothness are defined by quantization parameter available in the decoder and the difference between the pixels.

2.1 The proposed function

The blocking and ringing artifacts are caused by the quantization process of the DCT coefficients in the encoder, and the degradation model can be written as [1]

$$g(i,\ j) = f(i,\ j) + n(i,\ j) \qquad (1)$$

where *(i,j)* denotes the two dimensional coordinate to represent a pixel as shown in Fig. 1, and *g,f,n* are the compressed image, the original image, and the quantization noise, respectively. Then, the problem at hand is to obtain an image that is as close as possible to the original image. Since the above problem is ill-conditioned, the other constraints should be incorporated to obtain satisfactory results. The regularization theory has been used to replace the ill-posed

problem with well-posed problem by incorporating smoothness term into the solution [2]. In this proposal, the four directional filter to extract the discontinuities between the current pixel and its four neighboring pixels is defined, since the smoothness of a pixel is different in the each direction. The proposed function to incorporate the four directional smoothness can be written as

$$
\begin{aligned}
&M(f(i,\ j)) = M_L(f(i,\ j)) + M_R(f(i,\ j)) + M_U(f(i,\ j)) + M_D(f(i,\ j)),\\
&M_L(f(i,\ j)) = [f(i,\ j) - f(i,\ j-1)]^2 + \alpha_L(f(i,\ j))[g(i,\ j) - f(i,\ j)]^2,\\
&M_R(f(i,\ j)) = [f(i,\ j) - f(i,\ j+1)]^2 + \alpha_R(f(i,\ j))[g(i,\ j) - f(i,\ j)]^2,\\
&M_U(f(i,\ j)) = [f(i,\ j) - f(i-1,\ j)]^2 + \alpha_U(f(i,\ j))[g(i,\ j) - f(i,\ j)]^2,\\
&M_D(f(i,\ j)) = [f(i,\ j) - f(i+1,\ j)]^2 + \alpha_D(f(i,\ j))[g(i,\ j) - f(i,\ j)]^2, \qquad (2)
\end{aligned}
$$

where $M_L(f(i,j)), M_R(f(i,j)), M_U(f(i,j)),$ and $M_D(f(i,j))$ represent the functions to incorporate the smoothness in horizontal left, horizontal right, vertical up, and vertical down direction of *f(i,j)*, and $\alpha_L, \alpha_R, \alpha_U, \alpha_D$ denote the regularization parameters which define the degree of the smoothness in each direction. In Eq. (2), the first terms of each function represent the smoothness of the original pixel to the its neighboring pixels, and the second terms denote the fidelity to the data in each direction. To obtain the estimated pixel, $f(i,\ j)$, the differentiation of Eq. (2) with respect to *f(i,j)* leads to

$$
f(i,j) = \frac{f(i,j-1) + f(i,j+1) + f(i-1,j) + f(i+1,j) + \alpha(f(i,j))g(i,j)}{4 + \alpha(f(i,j))}, \qquad (3)
$$

where $\alpha(f(i,j)) = \alpha_L(f(i,j)) + \alpha_R(f(i,j)) + \alpha_U(f(i,j)) + \alpha_D(f(i,j))$. Here, there are two issues as follows: (1) how to obtain the *f(i,j-1),f(i,j+1),f(i-1,j),* and *f(i+1,j)* which are not available, and (2) how to calculate the regularization parameters. Since the estimated four neighbor pixels are not available, the compressed pixels are replaced for the original pixels of the right side in Eq. (3). The choice of the regularization parameters will be discussed in the next section.

2.2 The choice of the regularization parameters

The regularization parameters to control the relative contribution of the smoothness in each direction represent the ratio between the discontinuities of pixels and the fidelity to the original data. According to set theoretic approach[3], the parameters can be defined as

$$
\begin{aligned}
\alpha_L(f(i,\ j)) &= \frac{[f(i,\ j) - f(i,\ j-1)]^2}{[g(i,\ j) - f(i,\ j)]^2},\\
\alpha_R(f(i,\ j)) &= \frac{[f(i,\ j) - f(i,\ j+1)]^2}{[g(i,\ j) - f(i,\ j)]^2},\\
\alpha_U(f(i,\ j)) &= \frac{[f(i,\ j) - f(i-1,\ j)]^2}{[g(i,\ j) - f(i,\ j)]^2},\\
\alpha_D(f(i,\ j)) &= \frac{[f(i,\ j) - f(i+1,\ j)]^2}{[g(i,\ j) - f(i,\ j)]^2}. \qquad (4)
\end{aligned}
$$

In Eq. (4), it is impossible to obtain the exact quantization error. Therefore, the following is assumed; In order to define the bound of quantization error of each pixels, let us assume that the current macro block including *f(i,j)* is the l-th and its quantization parameter is represented by QP_l. Then maximum quantization error of DCT coefficients in the l-th macro block is equal to the quantization parameter. According to the Parseval's theorem, the total power of the

quantization error in DCT domain is equal to that in spatial domain. Also, if we assume that the quantization error of each DCT coefficient is equally distributed into all pixels belonging to the l-th macro block, $g(i, j) - f(i, j) = n(i, j) = QP_l$. Then, Eq. (4) can be rewritten as

$$\alpha_L(f(i,\ j)) = \frac{[g(i,\ j) - g(i,\ j-1)]^2}{QP_l^2},$$

$$\alpha_R(f(i,\ j)) = \frac{[g(i,\ j) - g(i,\ j+1)]^2}{QP_l^2},$$

$$\alpha_U(f(i,\ j)) = \frac{[g(i,\ j) - g(i-1,\ j)]^2}{QP_l^2},$$

$$\alpha_D(f(i,\ j)) = \frac{[g(i,\ j) - g(i+1,\ j)]^2}{QP_l^2}. \qquad (5)$$

2.3 Iterative solution

The direct solution in Eqs. (3) and (5), can be implemented in iterative method in order to more suppress the artifacts, since the real values in Eq. (3) are not used. In such case, the Eqs. (3) and (5) can be modified as iterative solution by

$$f_{k+1}(i, j) = \frac{f_k(i, j-1) + f_k(i, j+1) + f_k(i-1, j) + f_k(i+1, j) + \alpha_k(f_k(i, j))g(i, j)}{4 + \alpha_k(f_k(i, j))},$$

$$f_0(i, j) = g(i, j), \qquad (6)$$

and

$$\alpha_{k,L}(f(i, j)) = \frac{[f_k(i, j) - f_k(i, j-1)]^2}{QP_l^2},$$

$$\alpha_{k,R}(f(i, j)) = \frac{[f_k(i, j) - f_k(i, j+1)]^2}{QP_l^2},$$

$$\alpha_{k,U}(f(i, j)) = \frac{[f_k(i, j) - f_k(i-1, j)]^2}{QP_l^2},$$

$$\alpha_{k,D}(f(i, j)) = \frac{[f_k(i, j) - f_k(i+1, j)]^2}{QP_l^2}. \qquad (7)$$

In Eq. (6), $\alpha_k(f(i, j)) = \alpha_{k,L}(f(i, j)) + \alpha_{k,R}(f(i, j)) + \alpha_{k,U}(f(i, j)) + \alpha_{k,D}(f(i, j))$.

In summary, as shown in Eq. (4), it is clear that the recovered pixel is determined by the data fidelity and the discontinuities of the pixel to the neighbors, and the regularization parameters to determine the degree of the smoothness are estimated from the prior knowledge available in decoder. Therefore, no information is necessary to obtain the recovered image, and the expensive computational cost which is major disadvantage in regularized image restoration method as Ref. [4] is decreased.

3. Simulation Results

The proposed filtering is applied to TMN8 H263+ decoder, and is tested with several sequences and QP. Also, the proposed filtering with the direct approach in Eq. (4) and the two iteration in Eq. (6).are compared with the TMN8+TMN filter. As pointed out, the proposed 2D filtering is

independent on the encoder/decoder mechanism, so that the proposed filtering can be used to all hybrid MC DCT video codec to reduce the blocking artifacts and the ringing effects, resulting in increasing the visual quality and decreasing the complexity. In Fig. 2, the PSNR (peak to signal to noise ratio) plots of three different sequences ('hall objects', 'container', and 'silent voice') as a function of frame number are shown for 300 frames with different frame rates and different QPs. Also, the comparison of the average PSNRs and bit rates for several sequences are shown in Table 1. The experimental results show the capabilities of the proposed algorithm.

4. Future Investigation

When the other overhead information such as motion compensated frame and macro block type is incorporated into the modeling, the better results are expected, since the temporal correlation can be utilized into the solution. Also, the use of the proposed filter as a loop filter in the encoder and decoder is under investigation.

References

[1] A. K. Katsaggelos, ``Iterative Image Restoration Algorithm,'' *Optical Engineering*, vol. 28, no. 7, pp. 735-748, July 1989.

[2] M.-C. Hong, *Adaptive Regularized Image and Video Restoration*, Ph.D Thesis, Northwestern University, Dept. ECE, Dec. 1997.

[3] A. K. Katsaggelos, J. Biemond, R. W. Schafer and R. M. Mersereau, ``A Regularized Iterative Image Restoration Algorithm,'', *IEEE Trans. On Signal Processing*, vol. 39, no. 4, pp. 914-929, April 1991.

[4] Y. Yang, N. P. Galatsanos and A. K. Katsaggelos, ``Regularized Image Reconstruction from Incomplete Block Discrete Cosine Transform Data,'' *IEEE Trans. On Circuits and Systems for Video Technologies*, vol. 3, no. 6, pp. 421-432, Dec. 1993.

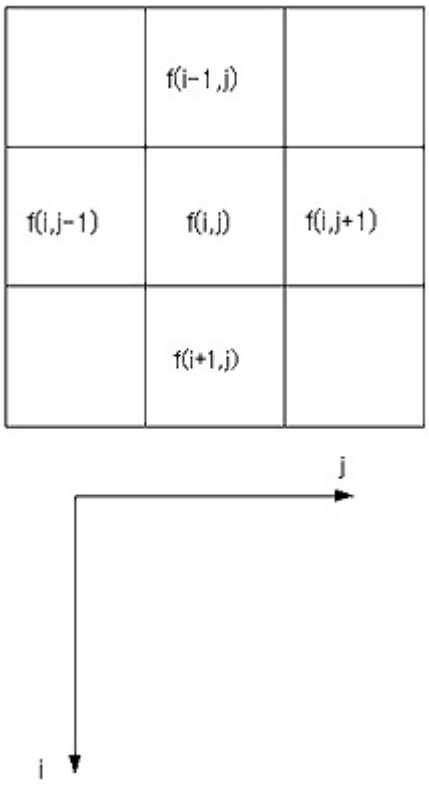
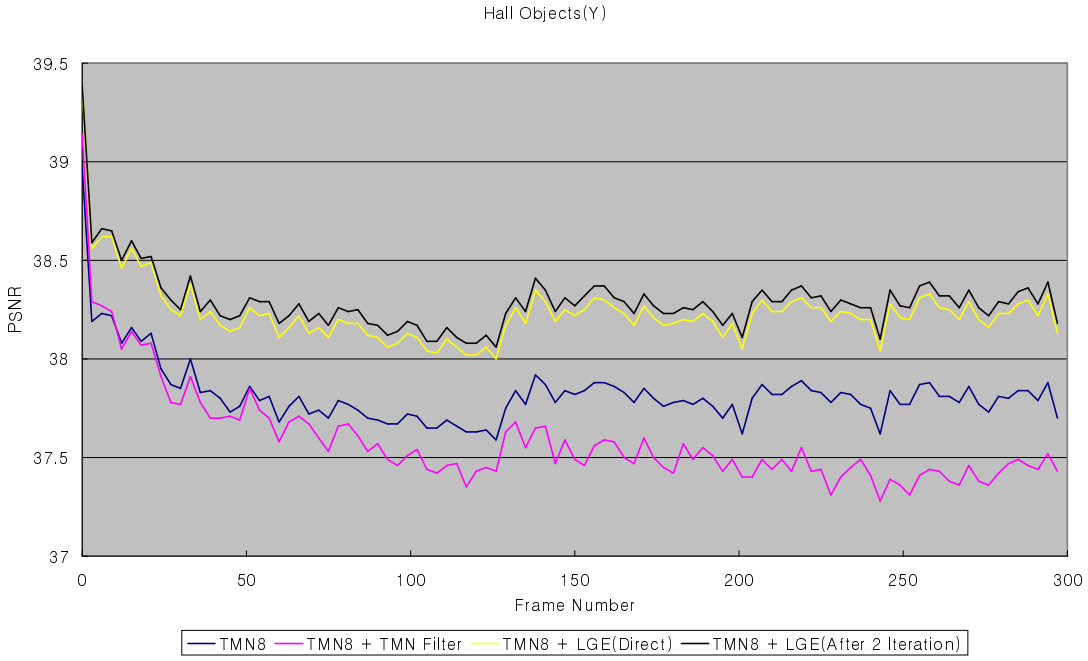
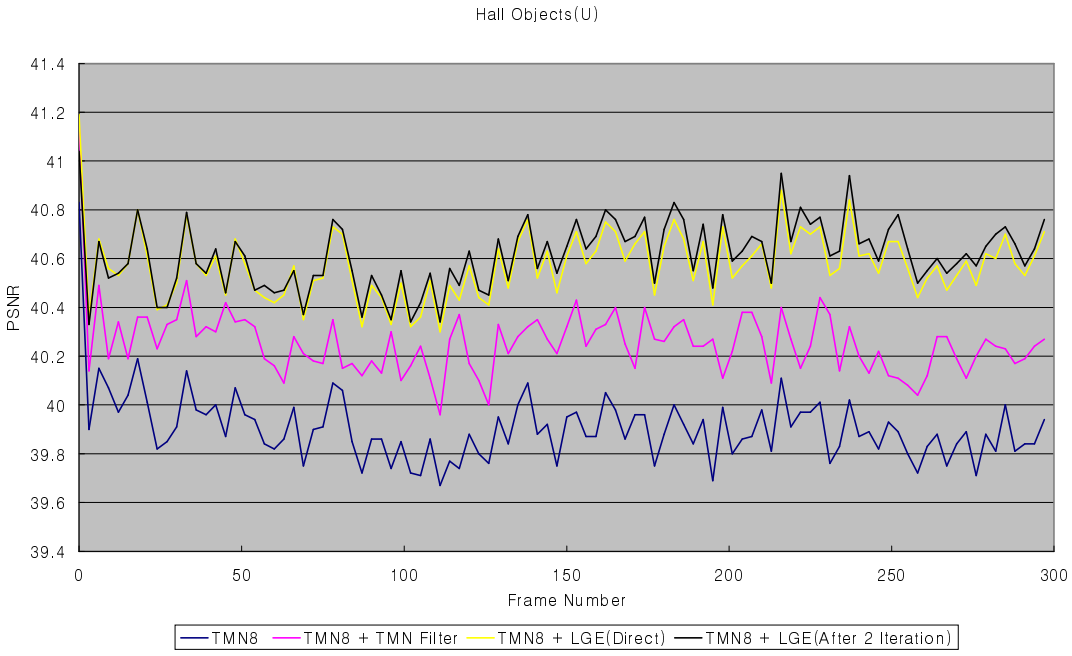
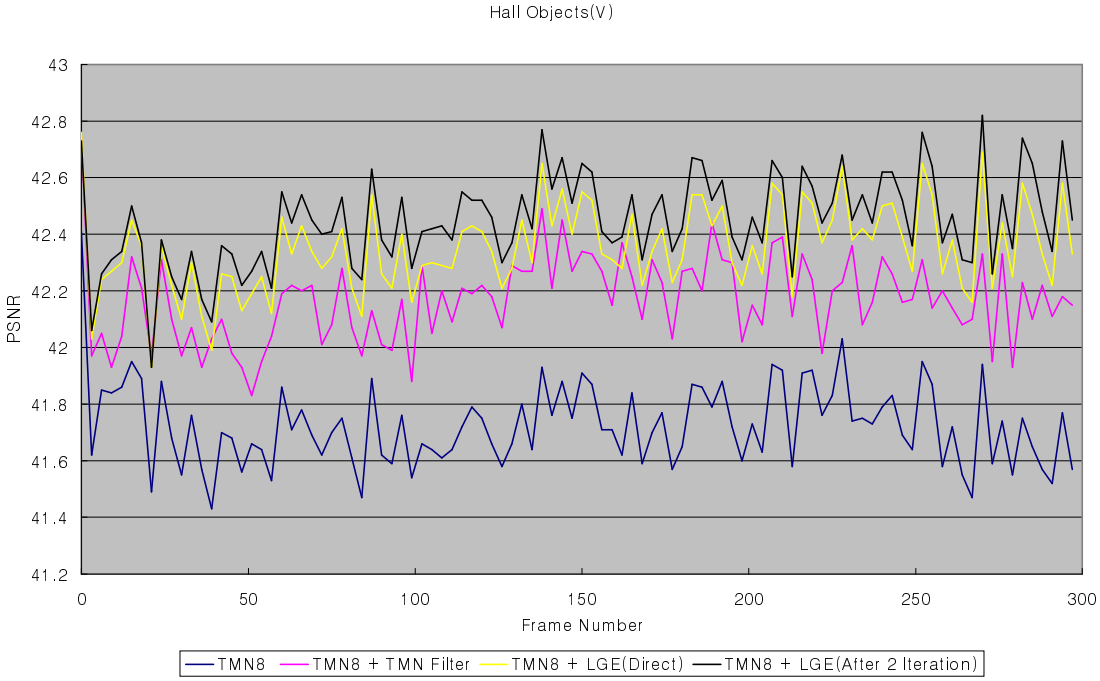


Fig 2. Two dimensional coordinate

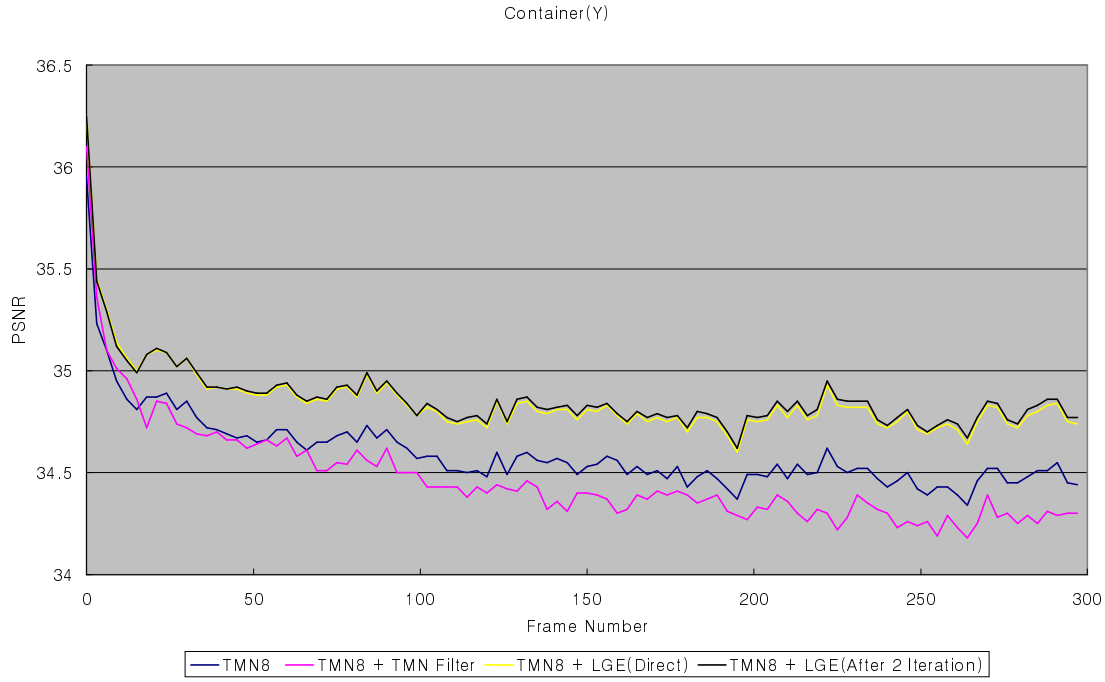
Hall Object

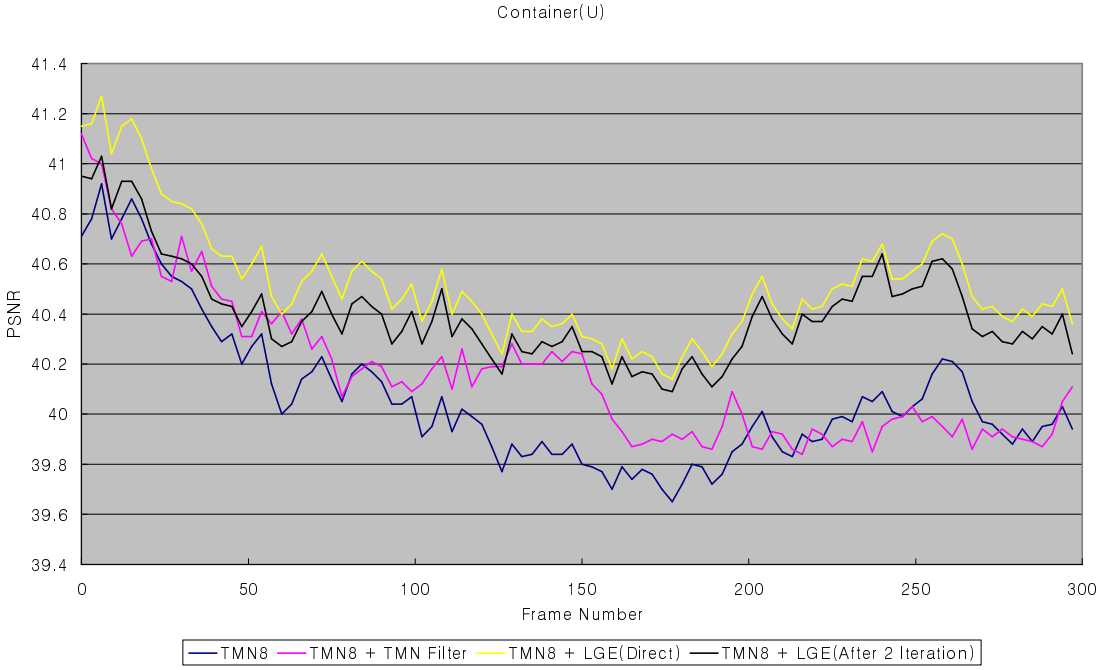

Hall Objects(Y)
PSNR
39.5
39
38.5
38
37.5
37
0
50
100
150
200
250
300
Frame Number
TMN8
TMN8 + TMN Filter
TMN8 + LGE(Direct)
TMN8 + LGE(After 2 Iteration)

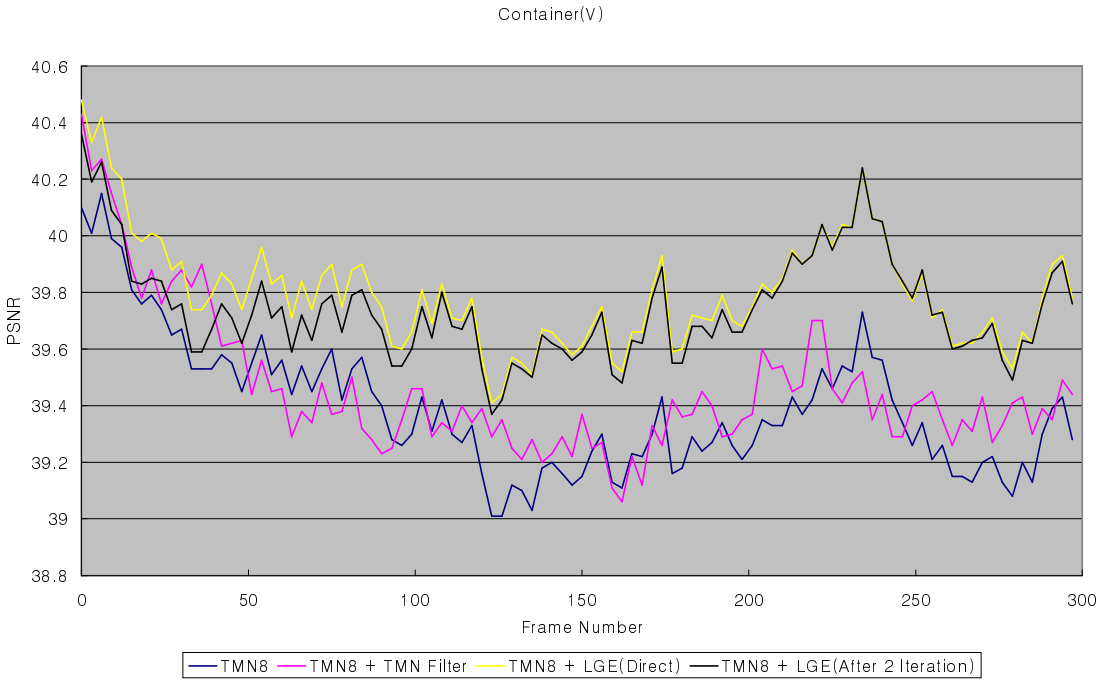

Hall Objects(U)
PSNR
41.4
41.2
41
40.8
40.6
40.4
40.2
40
39.8
39.6
39.4
0
50
100
150
200
250
300
Frame Number
TMN8
TMN8 + TMN Filter
TMN8 + LGE(Direct)
TMN8 + LGE(After 2 Iteration)


Hall Objects(V)
PSNR
Frame Number
TMN8
TMN8 + TMN Filter
TMN8 + LGE(Direct)
TMN8 + LGE(After 2 Iteration)

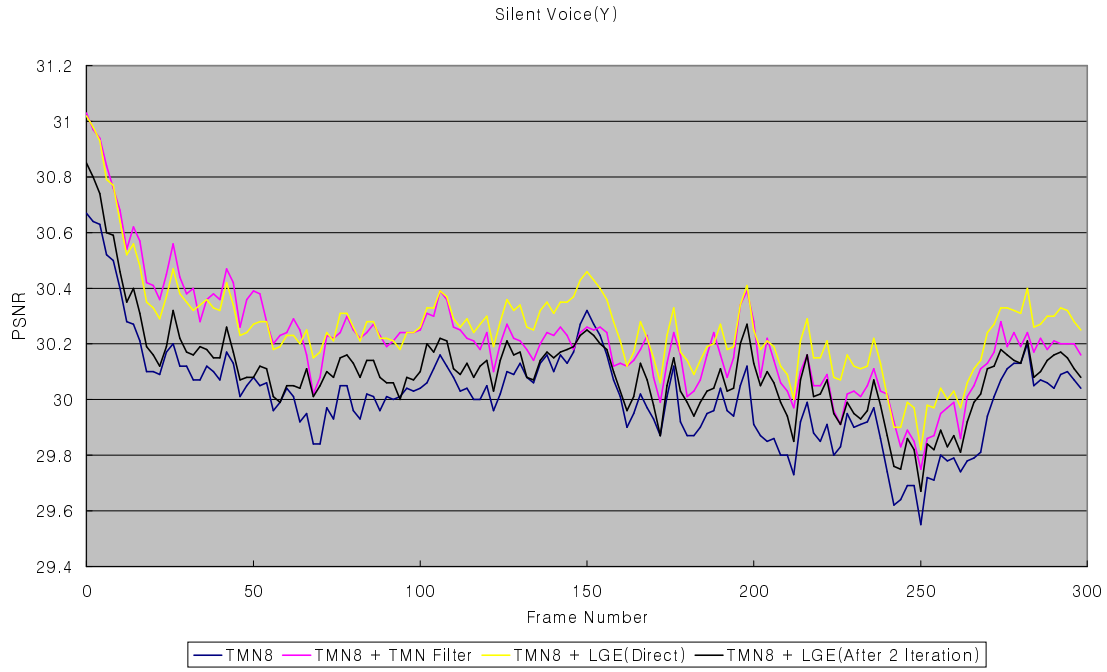
Container


Container(Y)
PSNR
Frame Number
TMN8
TMN8 + TMN Filter
TMN8 + LGE(Direct)
TMN8 + LGE(After 2 Iteration)


Container(U)
PSNR
41.4
41.2
41
40.8
40.6
40.4
40.2
40
39.8
39.6
39.4
0
50
100
150
200
250
300
Frame Number
TMN8
TMN8 + TMN Filter
TMN8 + LGE(Direct)
TMN8 + LGE(After 2 Iteration)


Container(V)
PSNR
40.6
40.4
40.2
40
39.8
39.6
39.4
39.2
39
38.8
0
50
100
150
200
250
300
Frame Number
TMN8
TMN8 + TMN Filter
TMN8 + LGE(Direct)
TMN8 + LGE(After 2 Iteration)

Silent Voice



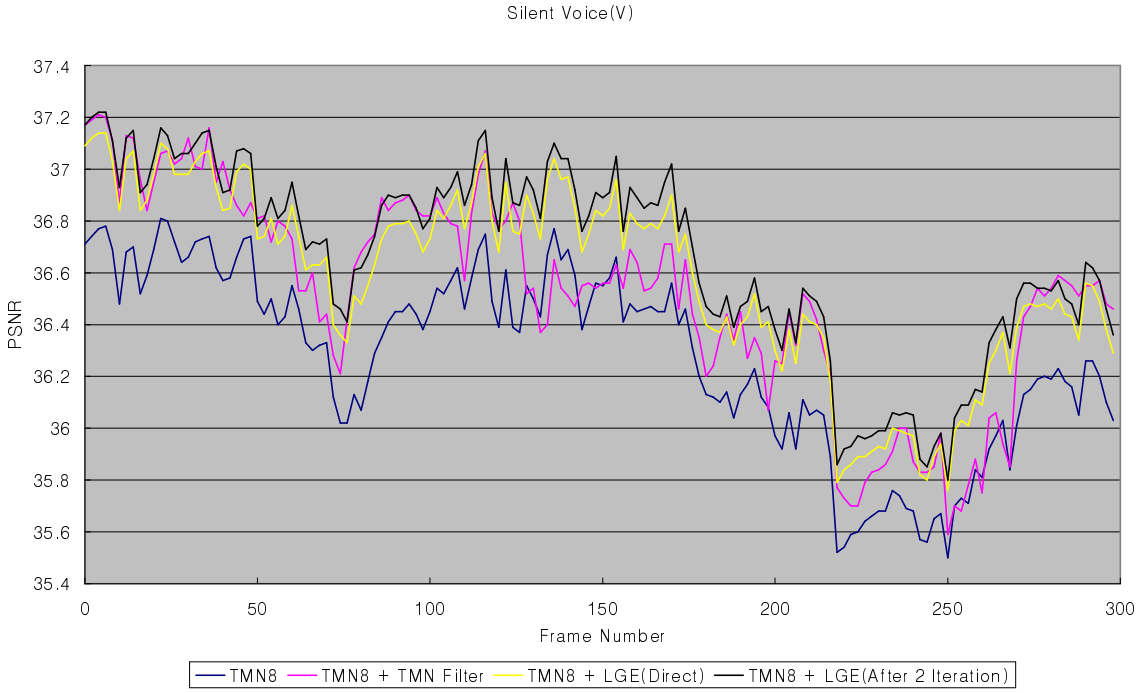


Fig 2. PSNR plots of hall objects, container, and silent voice sequences as a function of frame number

QCIF PSNR Comparison

Sequence	QP	Frame Rate	Frame Number	TMN8				TMN8+ TMN Filter				TMN8 + LGE(Direct)				TMN8 + LGE(After 2 Iteration)			
				Y	Cb	Cr	Bit Rate	Y	Cb	Cr	Bit Rate	Y	Cb	Cr	Bit Rate	Y	Cb	Cr	Bit Rate
Mother & Daughter	4	10	300	37.57	40.65	40.42	121.35	37.55	40.69	40.47	117.58	37.64	40.67	40.48	*	37.61	40.45	40.31	*
Hall Object	5	10	300	37.81	39.89	41.72	56.90	37.57	40.24	42.16	54.75	38.23	40.57	42.35	*	38.29	40.61	42.45	*
Hall Object	10	10	300	33.14	37.46	39.85	22.74	33.20	37.96	39.93	21.81	33.42	37.88	40.07	*	33.38	37.90	40.12	*
Container	7	10	300	34.58	40.06	39.38	38.21	34.45	40.15	39.45	38.04	34.85	40.52	39.80	*	34.86	40.40	39.71	*
Foreman	7	10	300	34.24	39.22	39.63	106.84	34.37	39.53	40.04	99.20	34.44	39.48	39.93	*	34.37	39.44	39.88	*
Foreman	15	10	300	30.00	36.43	36.48	42.06	30.13	36.94	36.89	41.08	30.05	36.68	36.73	*	29.86	36.71	36.72	*
News	15	10	300	30.05	34.59	35.96	22.73	30.13	35.22	36.43	22.43	30.21	34.84	36.28	*	30.06	34.77	36.31	*
Silent Voice	7	15	300	34.22	37.66	38.72	64.58	34.30	38.03	39.38	63.46	34.54	38.15	39.32	*	34.44	38.05	39.34	*
Silent Voice	15	15	300	30.01	34.57	36.28	24.57	30.21	34.88	36.52	24.82	30.26	34.91	36.58	*	30.10	34.94	36.66	*
Tour of Glasgow	10	15	750	30.94	37.13	39.20	108.54	31.06	37.58	39.57	104.21	31.10	37.56	39.61	*	31.02	37.59	39.69	*
Tour of Glasgow	15	15	750	28.77	35.66	37.84	66.02	28.94	36.12	38.24	64.07	28.93	36.11	38.26	*	28.80	36.22	36.38	*

CIF PSNR Comparison

Sequence	QP	Frame Rate	Frame Number	TMN8				TMN8+ TMN Filter				TMN8 + LGE(Direct)				TMN8 + LGE(After 2 Iteration)			
				Y	Cb	Cr	Bit Rate	Y	Cb	Cr	Bit Rate	Y	Cb	Cr	Bit Rate	Y	Cb	Cr	Bit Rate
Paris	15	15	900	28.82	33.55	34.12	124.70	28.71	33.96	34.48	123.29	28.95	33.96	34.45	*	28.86	33.88	34.36	*
Irene	10	30	500	35.02	38.22	37.75	239.60	35.14	38.52	39.19	239.35	35.21	38.48	38.08	*	35.08	38.43	37.98	*
Irene	25	30	500	31.05	34.59	33.99	82.18	31.24	35.16	34.55	86.17	31.22	34.79	34.26	*	31.10	34.66	34.28	*

*Bit rates of TMN8 + LGE(direct) and TMN8 + LGE(After 2 Iteration) are same to those of TMN8
Unit of bit rate : Kbps

Table 1. Average PSNR and bit rates comparison