Composite Video Artifact Removal by Nonlinear Bilateral Filtering

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ABSTRACT

A large number of comb filtering techniques for a national television system committee (NTSC) or phase alternate each line (PAL) color decoding have been researched and developed for the last three decades[1-3]. Comb filtering can separately obtain the luminance and the quadrature amplitude modulation (QAM) modulated chrominance information from a composite video burst signal (CVBS). However there is a difficulty in extracting the luminance and chrominance components from a composite video image because the cross-talk between them gives undesirable image artifacts. The three-dimensional (3-D) comb filter using spatio-temporal filtering kernel and adaptive two-dimensional (2-D) neural-based comb-filtering approach was developed[4] to alleviate the dot crawl artifacts; however it shows limitation on color decoding. This paper presents an effective dot crawl artifact reduction algorithm in a composite video signal, in which undesirable dot crawl artifact is significantly reduced without losing fine image details. The proposed composite video artifact removal algorithm filters only detected candidate regions specified by dot crawl artifact decision map. The possible comb-filtering error region is generated on video image using luminance and chrominance edge information. Simulation and analysis show that the proposed algorithm with nonlinear bilateral filtering removes efficiently the dot crawl artifacts on composite video image and supports improving further video enhancement techniques.

Keywords: Composite video, Nonlinear, Bilateral filter

1. INTRODUCTION

The difficulty in color decoding of CVBS introduces the dot crawl and hang dot artifact because the luminance and the quadrature amplitude modulation (QAM) modulated chrominance information shares single-channel transmission[1]. The spectral overlapping of chrominance and luminance can be ideally filtered by comb filters but there is some practical limitations[1-4]. Because applying image enhancement techniques to input video image with undesirable artifacts can be accentuated, the video image artifact removal process is required inevitably.

Nonlinear filtering techniques have been widely investigated despite of their difficulties in design and analysis because linear filtering algorithms based on sophisticated linear system theory tend to blur the sharp edges. Because the human vision is very sensitive to the edges in the image, linear filters are not effective. Nonlinear bilateral filtering algorithms gave satisfactory results with respect to edge preservation and efficient noise attenuation[7-8]. The properties of non-iterative bilateral filter have been investigated and developed in image processing techniques based on locally adaptive recovery paradigm compared to anisotropic diffusion, weighted least squares, and robust estimation[8]. Applying the bilateral filtering, we create the artifact decision map to detect error on decoding color of composite video signal. Edge detection masks, including Prewitt's mask, Robert's mask, and Sobel's mask, are well developed[5] and Canny's edge detection can give optimal results on noisy images[6]. Because ideal filtering process reduces the artifact and gives prefect reconstruction, the proposed method utilizes the disharmonious edge information between luminance and chrominance signal components as possible artifact containing regions. Practically, by assuming the error in comb filtering process, we apply boost up to the limited bandwidth of video images.

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Visual Communications and Image Processing 2005, edited by Shipeng Li,
Fernando Pereira, Heung-Yeung Shum, Andrew G. Tescher, Proc. of SPIE Vol. 5960
(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.631409

2. NTSC ENCODING/DECODING PROCESS

The compatibility consideration with its predecessor black-and-white television system based on 525 lines and 60 fields per second with interlaced scanning method was resolved by NTSC television system design. In order to accommodate the wider bandwidth requirement in color television transmission, they use YIQ color coordinates and modulate chrominance components using the quadrature amplitude modulation (QAM), as shown in Fig. 1.

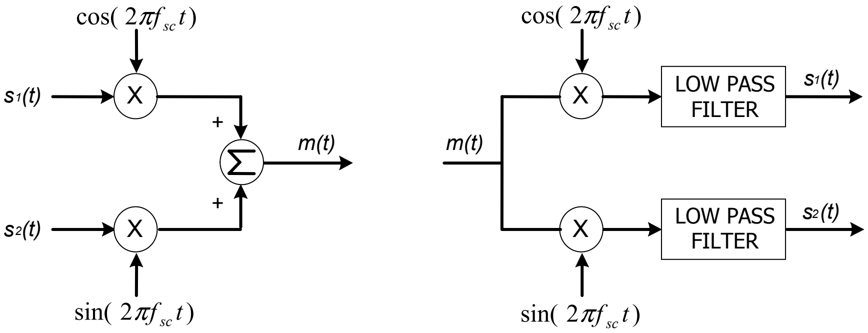


Figure 1. QAM modulation and demodulation

A spectral diagram of NTSC color television transmission system is shown in Fig.2 and satisfies the 6 MHz bandwidth requirement by federal communications commission (FCC). Chrominance components are multiplexed onto the color sub-carrier frequency and occupied in 4.2 MHz of luminance signal bandwidth.

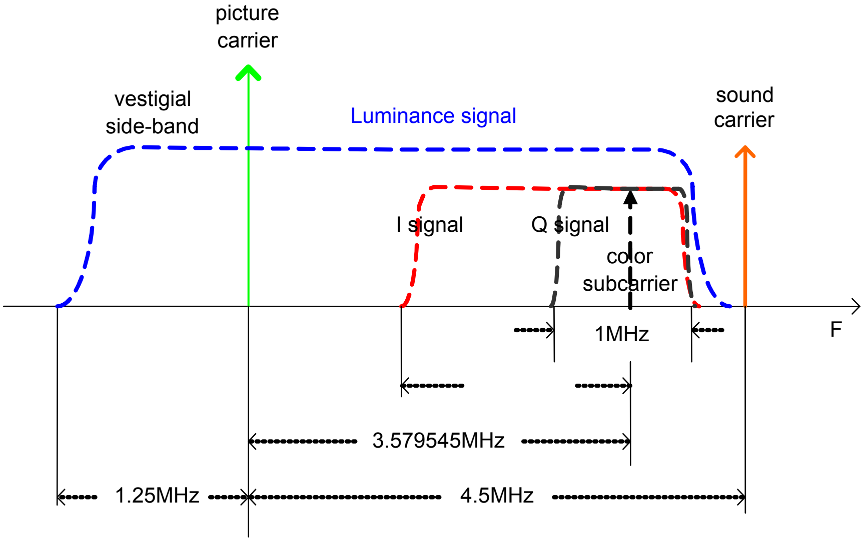


Figure 2. NTSC composite color TV spectrum

The composite video burst signal (CVBS) is composed by summing luminance signal and modulated chrominance signals having the same sub-carrier frequency but 90 degree shift.

$$CVBS(t) = Y(t) + C(t)\,, \tag{1}$$

$$C(t) = I(t)\cos(2\pi f_{sc} t + 33°) + Q(t)\sin(2\pi f_{sc} t + 33°)\,, \tag{2}$$

where I and Q are chrominance signals in NTSC YIQ color coordinate space respectively and f_{sc} is the color sub-carrier frequency. In Fig.3, we show luminance and chrominance spectra components interleaved horizontally and location of color sub-carrier frequency and where F_h is the horizontal scan frequency.

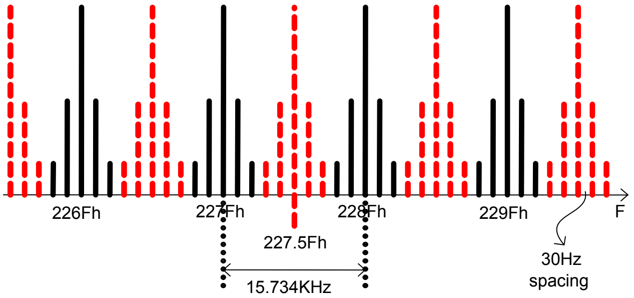


Figure 3. Luminance/chrominance horizontal frequency interleaving

NTSC composite color video coding process is shown in Fig. 4[13] and simulation of encoded NTSC video signal is illustrated in Fig. 5. Because the human vision systems are less sensitive to change in chrominance than to change in luminance and to the green-purple range Q than to the orange-cyan range I chrominance components, I and Q are bandlimitted to 1.5 MHz and 0.5 MHz respectively and occupied in the narrower bandwidth than Y component[12].

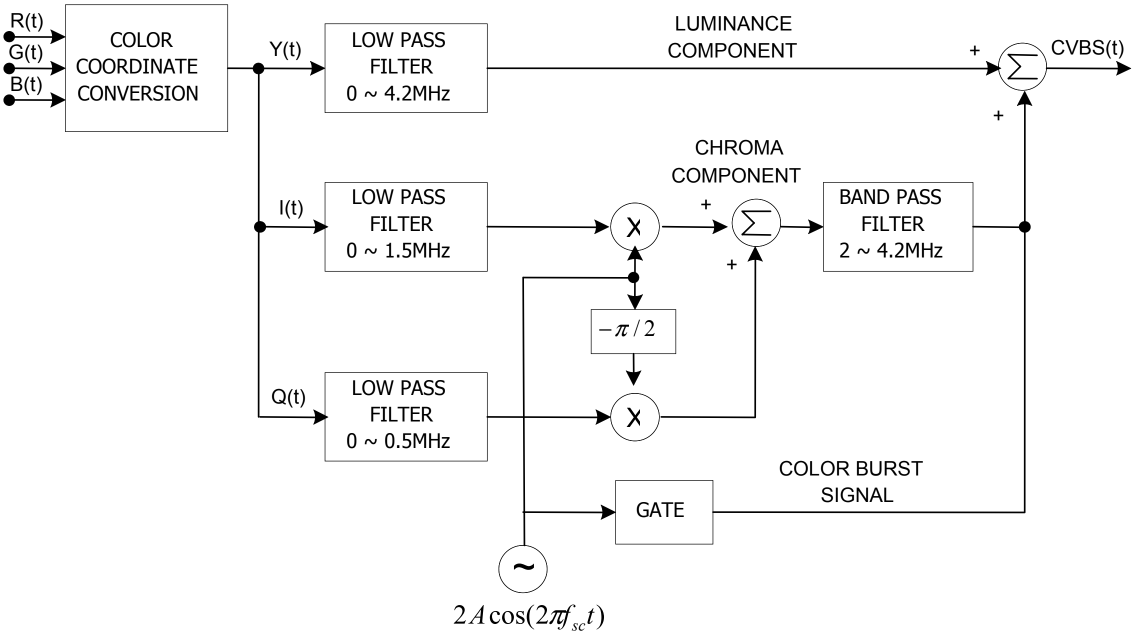
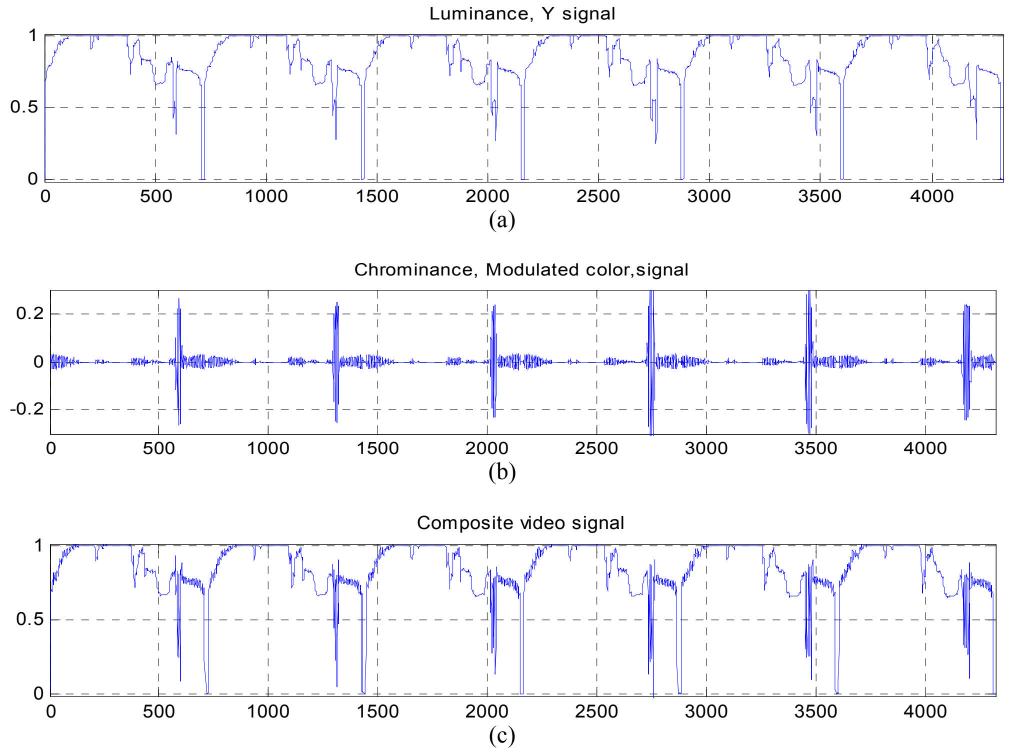


Figure 4. NTSC composite color video signal coding process



(a) (b) (c)

Figure 5. Six consecutive lines of NTSC composite color video signal; (a) luminance signal, Y(t) (b) chrominance signal, C(t) (c) composite video signal, CVBS(t) = Y(t) + C(t)

Decoding NTSC composite video signal process is shown in Fig. 6[13]. When low pass filter with cut-off frequency at 3 MHz is applied to retain luminance and chrominance components separately, high-frequency region of chrominance component possesses residual luminance signal. Thus extracted chrominance components contain significant luminance signal on a video image with very high frequency resulting color bleeding artifacts[12]. Ideal comb filter can extracts luminance signal component without the harmonic peaks of chrominance signal, which is not possible in practice. Residual chrominance on the extracted luminance signal yields to undesirable dot-crawl and/or hang-dot artifact.

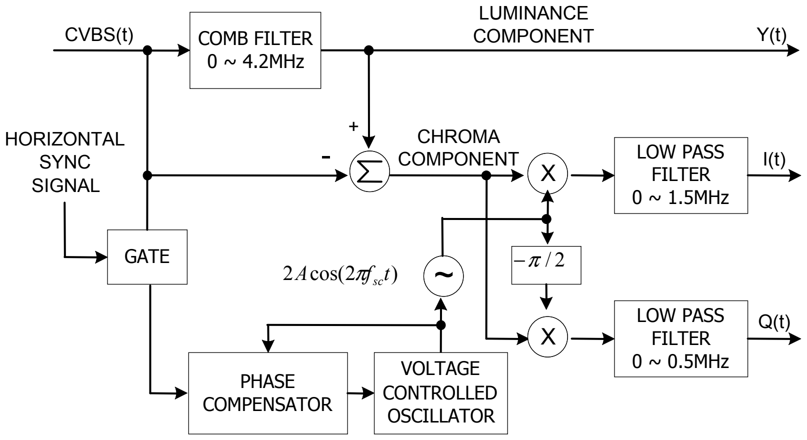


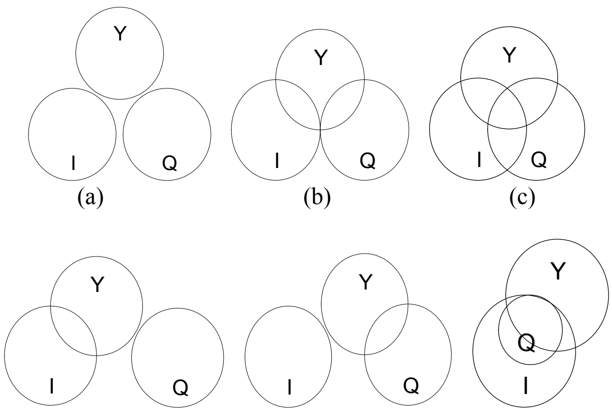
Figure 6. NTSC composite color video signal decoding process

3. ARTIFACE DECISION MAP

To reduce artifact from a given unknown video image, we use the artifact decision map that provides the distribution information of the artifacts existence. When the Y/C separation filter performs perfectly decoding the color of CVBS signal, each component is mutually exclusive, i.e.,

$$(Y \cap I \cap Q) = \varnothing \tag{3}$$

where Y, I, and Q are luminance and chrominance components, respectively, whose relationship is shown in Fig. 7(a). Otherwise, the video image can suffer from the artifact. The Y/C intersection is most likely to contain the harmonic peaks and/or high-frequency components in regions, i.e., edges and details on video images. Thus the intersection can produce the dot crawl artifact and resides in the spectral overlapping of chrominance and luminance, which is shown in Figs. 7(b)-7(f). By deductive reasoning, edge information of both chrominance and luminance video signal components will be mismatched on the intersection of Y/C domain.



(a) (b) (c)

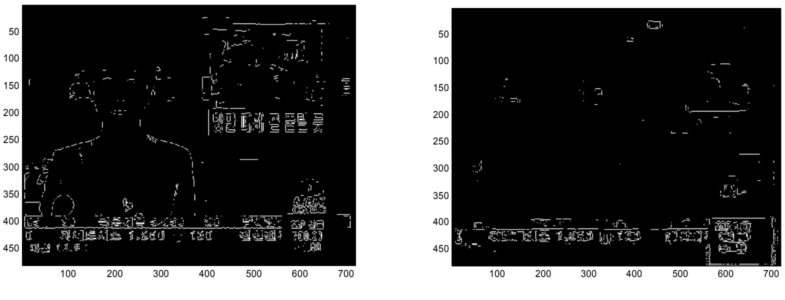
(d) (e) (f)

Figure 7. Color decoding: luminance and chrominance component separation; (a) ideal separation (b) overlapped Y / I and Y / Q (c) overlapped Y / I / Q (d) overlapped Y / I (e) overlapped Y / Q (f) overlapped Y / I / Q and I includes Q

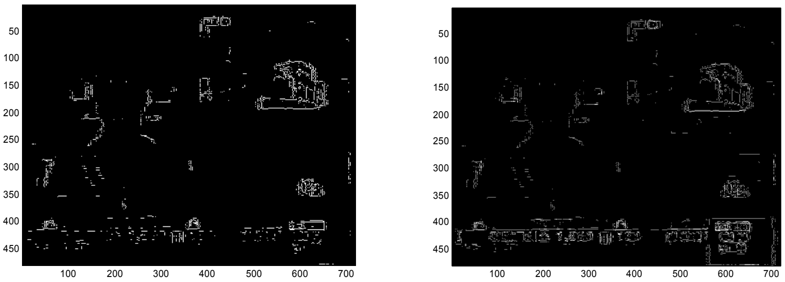
Therefore the artifact decision map can be generated as the following

$$(edge_I \cup edge_Q) - [(edge_Y \cap edge_I) \cup (edge_Y \cap edge_Q)] \tag{4}.$$

where, $edge_Y$, $edge_I$, and $edge_Q$ parameters represent sets of edges on Y, I, and Q, respectively. By constructing the artifact decision map shown in Fig. 8, the proposed method can achieve filtering without losing edges and details. Note that the proposed method will not degrade black-and-white video images because the black-and-white images do not produce any edge information for chrominance.



(a) (b)



(c) (d)

Figure 8. Edge detection in video image; edges in (a) Y component (b) I component (c) Q component (d) artifact decision map

In Figs. 8-9, we apply the proposed algorithm to construction of the corresponding artifact decision map. The artifact region is extended over not only on object area but also computer-generated graphics area including texts and icons.

(a) (b)

Figure 9. Artifact decision map; (a) input video image (b) detected artifact on video image

A non-ideal comb-filtering process is performed on the input video image in real video processing and it degrades the region that contains color sub-carrier frequency components. In this region, we reconstruct the original video with a band boost-up filter, as shown in Fig. 10. This linear filtering accentuates the artifact and gives sharper edges on luminance components.

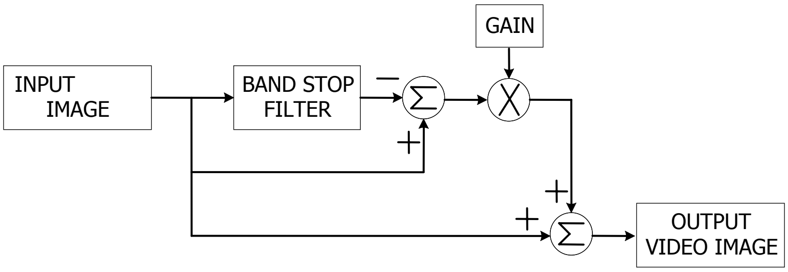


Figure 10. Imperfect comb filtered video image restoration

4. NONLINEAR BILATERAL FILTER

According to the artifact decision map, nonlinear bilateral filtering consisting of domain filtering and range filtering is performed. The bilateral filter can be designed with a metric system (Euclidean metric, 2nd norm) and the smoothing decaying function (Gaussian function)[8]. The non-iterative bilateral filter analysis is well developed and analyzed[7-8]. We can model a crawling dot pattern image as follows

$$y[n] = x[n] + d[n], \tag{5}$$

where $y[n]$, x[n], and $d[n]$ are the dot crawling image, the original image, and crawling dot pattern, respectively. To find the solution $x[n]$ from $y[n]$, we can formulate an optimization problem with a deviation penalty term and an additional constraint term, roughness penalty:

$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \left\{ \left\| \mathbf{x} - \mathbf{y} \right\|_2 + \tfrac{\lambda}{2} \sum_m \left\| \mathbf{x} - \mathbf{D}^m \mathbf{x} \right\|_{\mathbf{W}(\mathbf{x},m)} \right\}, \tag{6}$$

where **D** is one-sample shift matrix and λ is a Lagrangian multiplier. The second term of the cost function, roughness penalty term indicates image smoothness using the weighted norm of neighborhood of the signal. Applying the steepest descent optimization algorithm, the optimal $\hat{\mathbf{x}}$ can be obtained with infinitely many iteration steps. By delta rule, the intermediate estimated data is expressed as

$$\mathbf{x}^{(k)} = \mathbf{x}^{(k-1)} - \mu \left[\mathbf{I} + \lambda \sum_m (\mathbf{I} - \mathbf{D}^{-m}) \mathbf{W}(\mathbf{x}^{(k-1)}, m)(\mathbf{I} - \mathbf{D}^m)\mathbf{x}^{(k-1)} - \mathbf{y} \right], \tag{7}$$

where μ is step size parameter and (k) indicates the number of iterations. To obtain a non-iterative solution, we can determine the solution at the first iteration. And, if we set the initial value to y, the estimated x becomes

$$\hat{\mathbf{x}} = \mathbf{x}^{(1)} = \left[(\mathbf{I} + \lambda\mu \sum_m (\mathbf{I} - \mathbf{D}^{-m}) \mathbf{W}(\mathbf{y}, m)(\mathbf{I} - \mathbf{D}^m) \right] \mathbf{y}. \tag{8}$$

If we choose the weight with a range weight that is dependent on the pixel intensity difference and a domain direction weight, equation (8) goes to be a bilateral filter[8]

$$\mathbf{W}(x,m) = \mathbf{W}_R(x,m) W_D(m). \tag{9}$$

Dot crawl patterns more visually presents around edge regions because residual chrominance harmonic peaks are located on high-frequency luminance component and corresponding phase difference between lines generate artifact patterns. To remove crawling dot patterns with preserving edges, we choose the range weights

$$w_R(d) = \frac{1}{1 + e^{(d-Th)/Tr}}, \tag{10}$$

where $d = |y[n] - y[m]|$, and Th and Tr are threshold and transition parameters that control curvature and inflection point of the range weight function, respectively. This range filter's characteristics are shown in Fig. 11.

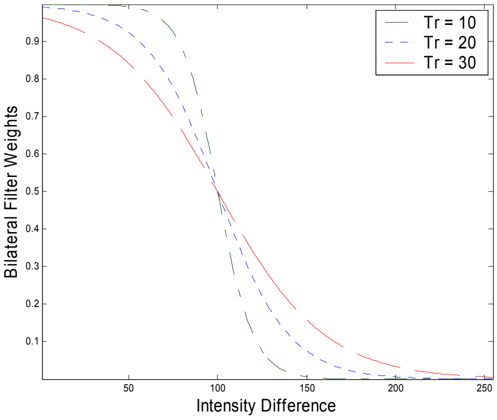
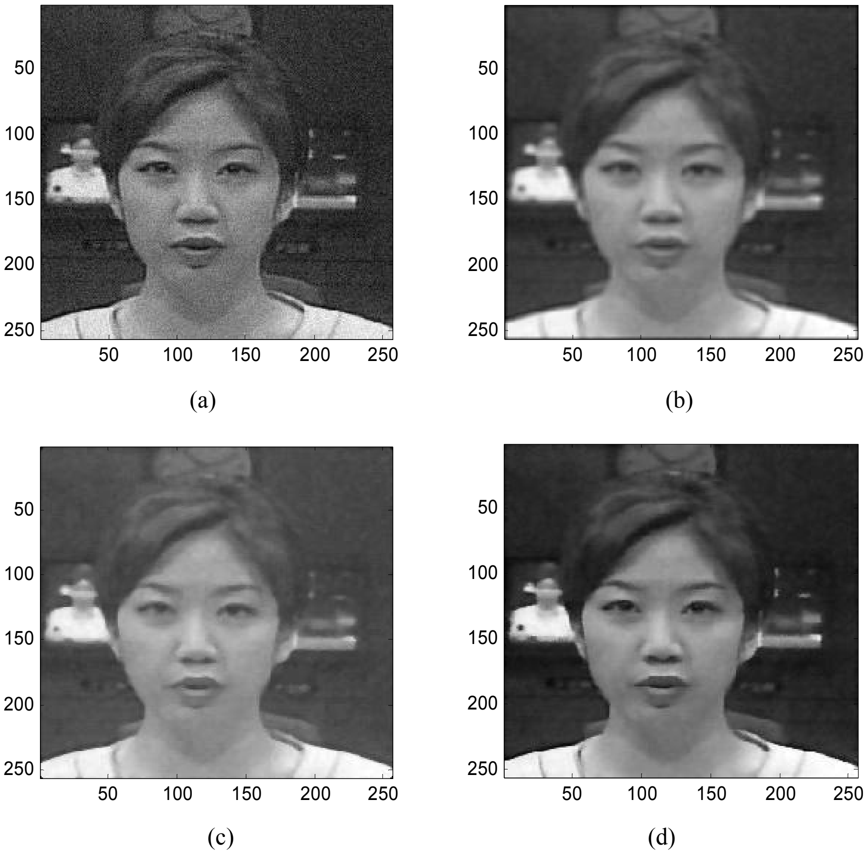


Figure 11. Range filter (bilateral filter weight) characteristics depending on Tr at Th = 128

For domain filter, the Gaussian filter is utilized [7] as an image smoothing filter. To preserve sharp image, a broad band filter can be considered as a domain filter, since the domain filter also makes additional blurring in the output image. In Fig. 12, we apply the averaging low pass filter, median filter, and bilateral filter to an image contaminated by additive white Gaussian noise with variance equal to 0.001, which shows the efficient performance of the nonlinear bilateral filter.



(a) (b) (c) (d)

Figure 12. Filtering example of noisy input image; (a) image with white Gaussian additive noise (variance = 0.001) (b) low pass filter by averaging (mask size, 5X5) (c) median filtered and (d) nonlinear bilateral filtered image

5. RESULTS

The composite video image artifact removal process is shown in Fig. 13. We apply the down-sampling and interpolation to the chrominance signal for smoothing purpose because it can produce better results perceptually. Furthermore the different metric system, the smoothing decaying function, and the various range and domain parameter values can affect the resulting video image.

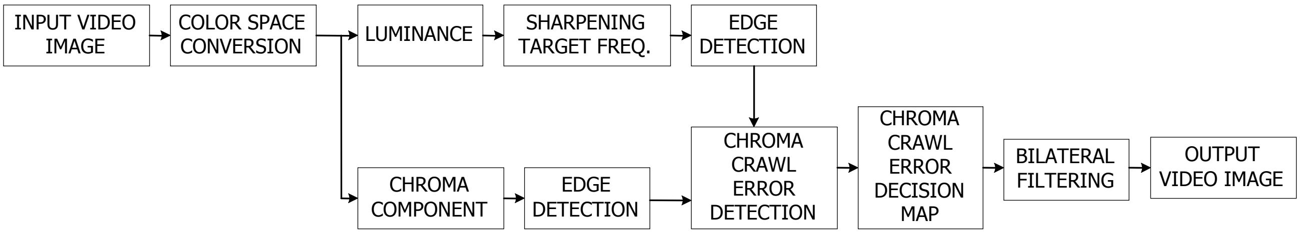


Figure 13. Composite video artifact removal according to the artifact decision map

The proposed method is experimented with the computer-captured video image which suffers from the dot crawl artifact. The simulation result, shown in Fig. 14, proves the effectiveness of the proposed method in terms of the image quality. Figs. 14(b) and 14(c) enhanced by the conventional method and comb-error compensated method, respectively, shows limitations, whereas Fig. 14(d) by the proposed method shows satisfactory results. For better video enhancement processing, the proposed method can be used as a pre-filter. In addition, the proposed method preserves edges or details by using a nonlinear bilateral filter according to the artifact decision map information.

6. CONCLUSION

In order to accommodate its predecessor, NTSC resolves the compatibility problem between color and black-and-white television transmissions. However corresponding bandwidth requirement and sophisticated NTSC color decoding system yield to undesirable artifacts including dot crawl, hanging dot, and color bleeding. Ideal color decoding processing of composite video signal is inevitably required because inadequate Y/C separations cause a residual chrominance of extracted luminance signals. Because of the fact that human vision is very sensitive to the edges and inadequately decoded composite signals on real video images suffer the crawling dot patterns around edges, in addition, further applying video enhancement algorithm accentuates the artifacts significantly at the edge regions, the consideration of edge preserving artifact reduction method is necessary. The introduced composite video artifact reduction algorithm based on artifact decision map and nonlinear bilateral filtering reduces undesirable dot crawl artifact efficiently without losing fine image details. Experiments support that nonlinear bilateral filtering to the detected artifact candidate regions improves effectively the quality of the NTSC decoded video images with respect to edge preservation and efficient noise attenuation. In addition, further applying video image enhancement techniques can be satisfactorily realized without exaggerating the composite video artifact by accommodating the proposed algorithm.

(a) (b)

(c) (d)

Figure 14. Simulation result with dot crawl artifact; (a) input image (b) image enhancement (c) comb error compensated image (d) image enhancement with proposed filtering

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