A Motion-Adaptive De-interlacing Method Using an Efficient Spatial and Temporal Interpolation

Sung-Gyu Lee and Dong-Ho Lee

Abstract — *This paper proposes a motion-adaptive de-interlacing algorithm based on an edge-based median filter (EMF) and adaptive minimum pixel difference filter (AMPDF) To compensate for missing-motion error, which is an important factor in motion-adaptive methods, we used an AMPDF, which estimates an accurate value using different thresholds after classifying areas of the input image into 3 classes. To efficiently interpolate moving diagonal edges, we used an EMF, which adopted a 5-point median filter using the edge information. Finally, to increase the performance, we adopted adaptive interpolation after subdividing the input image into moving, background, and boundary regions. Simulation results showed that the proposed method performs better than existing methods.*

Index Terms — de-interlacing, digital TV, interpolation, motion-adaptive

I. Introduction

De-Interlacing is the essential element that supports the standard formats adopted for digital TV in the development of digital TV receivers. Various methods of de-interlacing have been presented. For the most part, these methods can be categorized as MC (motion-compensated) and No-MC (not motion-compensated) methods. No-MC methods include methods of motion-adaptive application that depend on the motion and approaches that use various spatial interpolation filters [1]-[10]. The edge-based line average (ELA) method is widely used, since it involves simple calculation and convenience [2]. The ELA method extracts edge information and calculates the average between lines. It has shortcomings, however; it can use the wrong edge information and is sensitive to small pixel values. MC de-interlacing methods produce errors when estimating the motion and involve many calculations and a complex structure [5].

In motion-adaptive No-MC methods, it is important to extract the exact moving and background areas, as well as the exact edge map, for the spatial filter using this information, and effective spatial and temporal interpolation methods are necessary [3][6][7]. In general, the motion information is obtained by comparing pixel values in three reference fields, and if the difference exceeds a threshold value, considering this a 'moving' pixel. There are limitations in obtaining the exact information, and any missing area of motion generated in this way causes a rapid deterioration in picture quality.

A spatial filter extracts an edge map first, and determines the appropriate pixel values from this. Extracting the exact edge map is the element that determines the performance of the method. However, most edge detection methods have a weakness in their ability to determine diagonal edges, and the direction of the obtained edge cannot be fully trusted.

To solve these problems, this paper proposes a motion-adaptive de-interlacing algorithm based on an edge-based median filter (EMF) and a 3-step adaptive minimum pixel difference filter (AMPDF). To prevent errors resulting from missing motion, this paper proposes an AMPDF that interpolates the exact pixel value by subdividing the input image to three regions and using a different threshold value for each. This paper also improves the performance of the method by using a new EMF that selects potential pixels that vary, depending on the edge, in order to remove the error due to false motion; this is effective for interpolating moving diagonal edges. The input image is subdivided into the moving, background, and boundary areas, and adaptive interpolation is used to improve the performance.

This paper is organized as follows. Part II briefly explains existing de-interlacing algorithms, and Part III explains the proposed de-interlacing algorithm. Part IV compares and analyzes the existing methods and the proposed algorithm through a computer simulation, and Part V contains the conclusions.

II. Problems With Conventional Methods

The simplest No-MC method is the line average method, and the edge-based line average (ELA) is an improvement on this. The ELA is widely used, due to its convenience of implementation and the small amount of calculation required; however, it causes deterioration in picture quality when treating slowly moving diagonal edges or areas with movement [1]-[3]. Therefore, it is frequently used as a spatial filter for motion-adaptive methods, rather than as an independent method.

Representative motion-adaptive methods include a method that uses the brightness profile pattern [6] and the GA HDTV de-interlacer [7]. The most important element in determining the performance of motion-adaptive methods is detecting the exact movement that divides the input image into areas with movement and the background area. Despite using four fields, including the front and back, the GA HDTV de-interlacer

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cannot detect movement properly, which results in missing motion and false motion. This shortcoming results in a rapid deterioration in picture quality. Since it performs line averaging with a spatial filter, it fails to interpolate moving edges effectively. It obtains pixel information from four reference fields to extract movement information, and uses three differences in pixel values from same-parity fields to remove the false motion among opposite-parity fields. Then, it sets the maximum value as the movement value. To interpolate the final pixel, it uses the value obtained with a temporal median filter and intra-field interpolation (line average) depending on movement information.

The brightness profile pattern method uses a profile pattern to extract movement information; this includes using the modified ELA method as a spatial filter and a mean filter as a temporal filter. In the modified ELA method, horizontal and vertical elements are obtained using a Sobel operator [2]; an edge map is extracted using the direction elements obtained; and a line average is obtained for the edge direction. Using the brightness profile pattern can prevent a rapid deterioration in picture quality, by comparing the pixel values in fields and the difference in the potential pixel values in the front and back fields over time, by removing the missing-motion error generated for areas with a small amount of local movement. However, it has a weakness, in that it generates false motion, since it sometimes considers edge areas without any motion as moving areas. In this case, it is necessary to apply a spatial filter to remove the false motion. Using incorrect edge information with the ELA method may cause deterioration in picture quality. Since the direction of edges detected is limited to -45, 0, and 45 degrees, deterioration in picture quality is inevitable for slowly moving diagonal edges.

III. The Proposed Algorithm

Fig. 1 is a block diagram of the proposed de-interlacer. In general, the most important steps in No-MC methods are removing false motion and missing motion, and effectively processing moving diagonal edges.

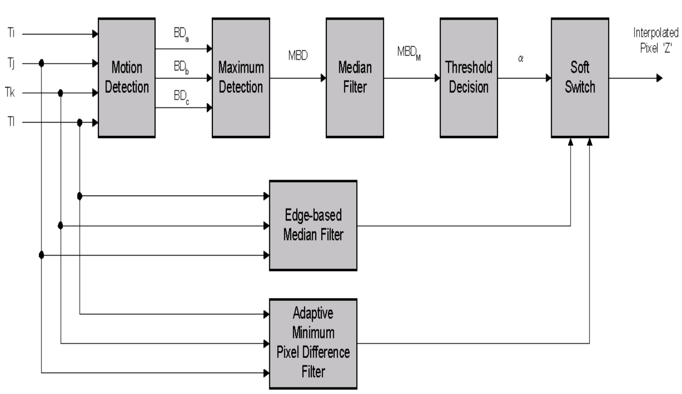


Fig. 1. Overall block diagram of the proposed algorithm

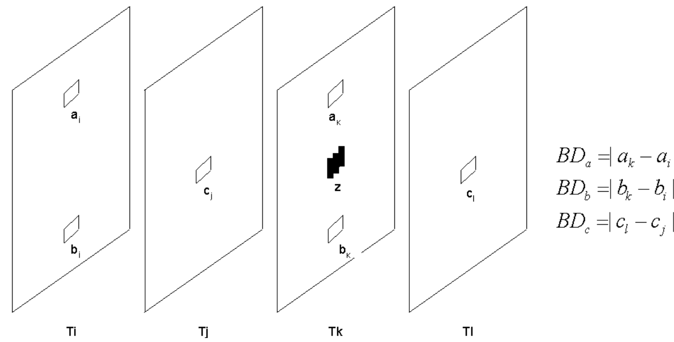


Fig. 2. Movement detection from four reference fields

A. Motion Detection and Threshold Decision

Movement information is obtained using the difference in the brightness of pixels in three reference fields. Fig. 2 shows how motion information is extracted from four reference fields. This expression is used to calculate the pixel-movement value at location "z". It has a weakness, in that a very small movement may not be detected in a specific area when calculating movement values using the difference in brightness. Here, it will not cause false motion to be generated near boundary areas, since the false motion that occurs in a specific area is compensated for by comparing the neighboring pixels through 3-step exploration using an AMPDF, as explained below. Movement information obtained in this way is passed through a 3-point median filter to remove the false motion due to the noise.

The input image of the obtained movement information can be subdivided into three areas: areas with much movement, boundary areas, and the background image. The area with much movement is interpolated by focusing on the spatial filter, since the spatial areas contain much information on the

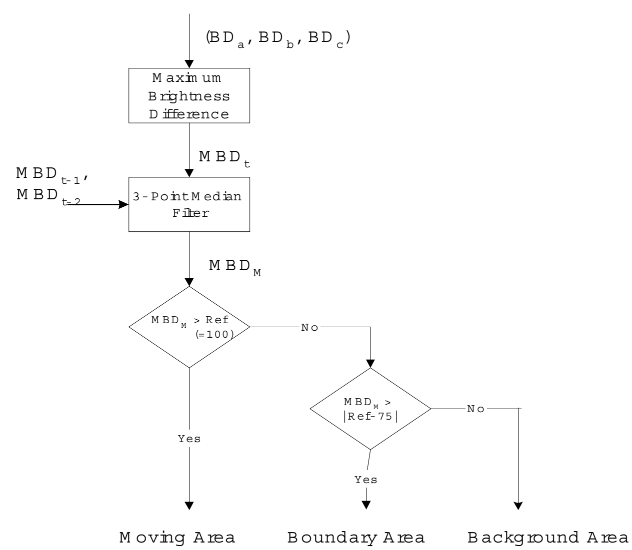


Fig. 3. Flowchart for classifying the input image into three types.

pixel value to be interpolated. The background area is interpolated with a greater emphasis on the temporal filter, since more information on the pixels exists in the temporal areas. Fig. 3 is a flow chart classifying areas of the input image into three regions.

B. Adaptive Minimum Pixel Difference Filter (AMPDF)

We propose a new 3-step exploration method to remove the error that is generated by missing motion. The following assumptions are made for missing motion:

1) The areas with missing motion are only generated in locally very small moving areas.

2) Missing-motion error is generated at the boundary between moving and background areas.

After subdividing the input image into the area with movement, the background area, and boundary areas using differences in brightness value, we apply different threshold values for each to improve the performance. In our experiment, the threshold values used in the proposed AMPDF are 70 for the moving region, and 15 for the boundary and background regions. We use a high threshold value for the moving area, since it is not necessary to carry out the 3-step exploration since a spatial filter is used. Since missing motion may occur at boundary areas, we use a low threshold value for these areas and carry out the 3-step exploration to ensure exact interpolation. Fig. 4 shows an example of selecting a potential pixel via three-step exploration. Fig. 5 is the flow chart used to explore the optimum pixel value via 3-step exploration. Here, the 3-tap median filter uses the pixel values at the same location in the previous and next fields, as well as the result of the first step search. The 3-step exploration procedure is as follows:

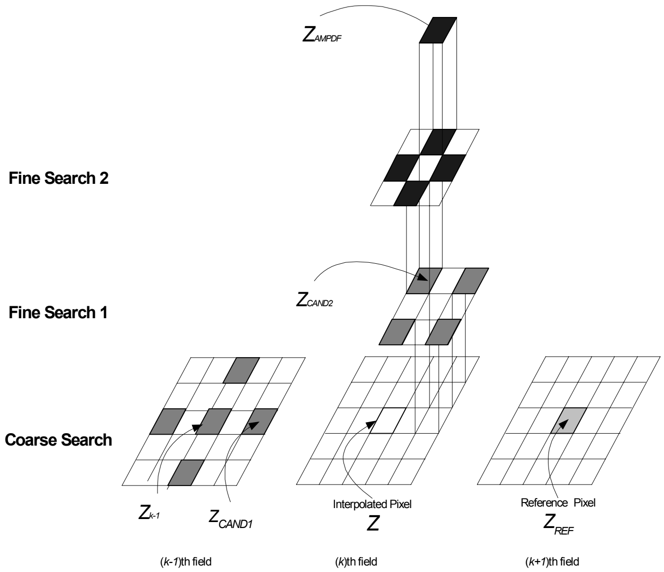


Fig. 4. An example case of a three-step search of the AMPDF

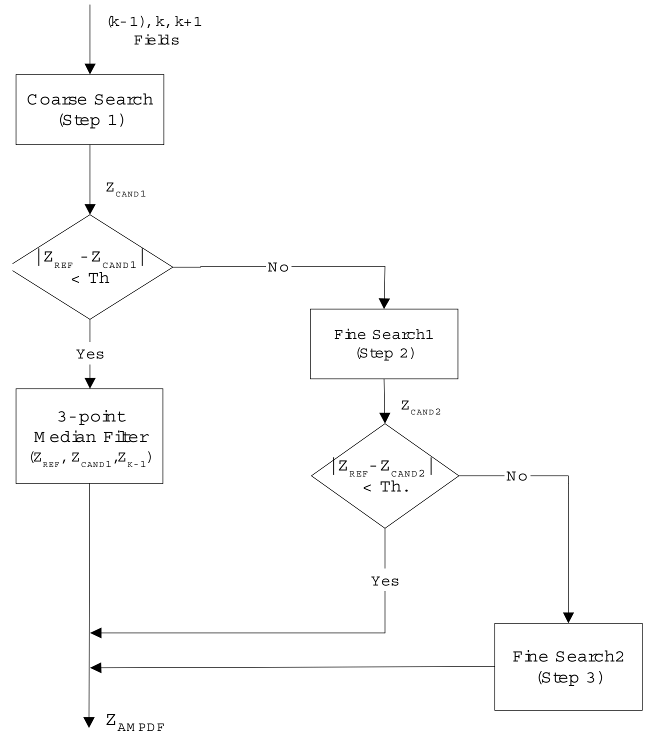


Fig. 5. Flowchart for deciding the final output using the AMPDF

Step 1 (Coarse Search)

First, obtain the AD (absolute difference) for 5 potential pixels located in the previous and next fields in terms of time, and select the pixel with the minimum difference. If the minimum difference is smaller than the threshold value, use the 3-tap median filter to obtain the final value to be interpolated. If it exceeds the threshold value, go to the next step.

Step 2 (Fine Search 1)

If the minimum difference obtained in the first step exceeds the threshold value, carry out the second step exploration. If the minimum difference obtained in the second step is smaller than the threshold value, select the pixel value as the final candidate. If it is bigger, carry out the third step exploration.

Step 3 (Fine Search 2)

Calculate the pixel value that has the minimum difference in the third step exploration. Since missing motion occurs in minute areas of movement in boundary areas, it is possible to completely remove the missing motion by making the threshold value smaller at boundary areas and carrying out the third step exploration.

C. Edge-based Median Filter (EMF)

Dealing with a moving diagonal edge is one of the important features determining the performance of the algorithm. The existing edge-based de-interlacing method enables the processing of edges with directions of 45, 0, or –45 degrees, but causes deterioration in picture quality for slowly changing edges. This paper proposes an edge-based 5-point median filter that deals with this problem. The performance for a slowly moving diagonal edge was improved by extracting the edge map using a 3×3 Sobel operator and a 7×3 mask, which is larger than the edge-detecting window. Edge maps were extracted in the horizontal and vertical directions by applying the operator vertically and horizontally to determine the direction. While a 3×3 window can extract edge maps for edges oriented at 45, 0, and -45 degrees, the 7×3 window detects gentle edges at 45, 30, 15, 0, -15, -30, and -45 degrees. Fig. 6 shows the procedure. The edge map in the 7×3 window is readjusted to remove incorrect edges and select consecutive edges on each line. The final potential edges are selected by giving a greater priority to edges that have more consecutive edges and are nearer to the interpolated pixel. We calculate the final pixel value for interpolation by using the 5-point median filter on the five candidates, as shown in (1). The five candidates are obtained by using the five possible combinations of edge information. The rules used to calculate the five candidates are listed in Table I.

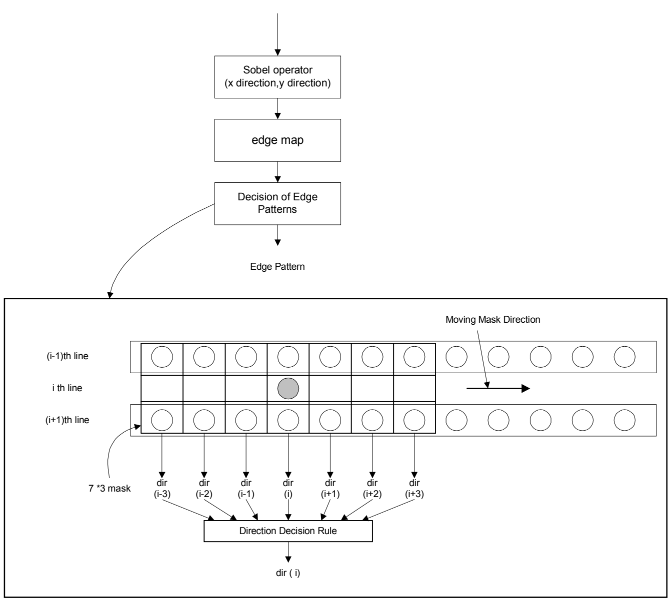


Fig. 6. Flowchart for deciding an edge map in a 7x3 window

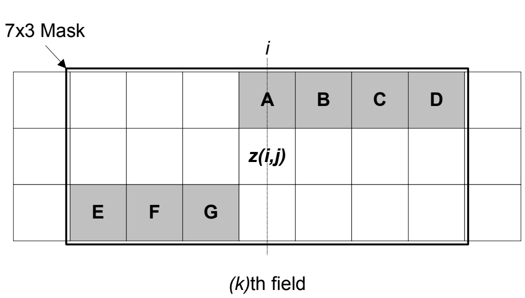


TABLE I
RULES FOR CALCULATING THE FIVE CANDIDATES

Candidates	Decision Rules
X_1	Average of all pixels on edge
X_2	Average of the pixel at the left end of the upper line and that at the right end of the lower line
X_3	Average of the pixel at the left end of the upper line and that at the left end of the lower line
X_4	Average of the pixel at the right end of the upper line and that at the right end of the lower line
X_5	Average of the pixel at the right end of the upper line and that at the left end of the lower line

Fig. 7. An example of an edge map in a 7x3 window

Fig. 7 shows an example of an edge map generated after filtering with the 7×3 window, and (2) lists the five candidates with an example of median filtering.

$$Z_{EMF} = Med(X_1, X_2, X_3, X_4, X_5) \quad (1)$$

$$\begin{aligned} X_1 &= (A + B + C + D + E + F + G)/7 \\ X_2 &= (A + G)/2 \\ X_3 &= (A + E)/2 \\ X_4 &= (G + E)/2 \\ X_5 &= (D + E)/2 \end{aligned} \quad (2)$$

D. Switch Block

This is a block that determines whether to use the value interpolated using the AMPDF in the above method as the final pixel value, whether to use the pixel value interpolated using EMF, or whether to use a combination of both. Equation (3) and (4) are the expressions used to determine the 'Z' pixel value to be finally interpolated, and the expression to determine the coefficient α, respectively. Here 'MBD_M' refers to the maximum brightness difference value that had to pass through the 3-point median filter to remove the noise.

$$Z = (1 - \alpha)*Z_{AMPDF} + \alpha * Z_{EMF} \quad (3)$$

$$\alpha = \begin{cases} 1 & \text{, for moving region} \\ \dfrac{MBD_M - 25}{100 - 25} & \text{, for boundary region} \\ 0 & \text{, for background region} \end{cases} \quad (4)$$

IV. SIMULATION RESULTS

Processing false motion, not missing motion, and moving diagonal edges are important in motion-adaptive de-interlacing methods. We used subjective picture quality evaluation in addition to the PSNR (peak signal-to-noise ratio) for an exact analysis of performance, since missing-motion error causes rapid deterioration in picture quality when it occurs, no matter how high the PSNR. The following methods were used to

TABLE II
TEST IMAGE CHARACTERISTICS

Test Image	Image Characteristics
Table Tennis	Some change, fast movement near the ball
Flower Garden	Includes moving diagonal edges and large amounts of change
Football	Generally fast moving
Susie	Almost still, with some change
Pop	Includes many thin edges, some changes

calculate the PSNR of the output image and for subjective evaluation, respectively.

1) The PSNR was calculated after interpolation by converting the 352×240 progressive image into an interlaced image with a 352×120 field structure, and applying each algorithm to the images.

2) The 704×480 progressive image was restored by applying the proposed algorithm to the bottom and top fields of the 704×480 interlaced image for a subjective evaluation of picture quality.

To compare performance, the methods using the brightness profile pattern (Modified ELA)[6], Line Average Method, and GA HDTV scan converter [7] were also examined. Test images used here included images of table tennis, a girl (Susie), a flower garden, football, and a pop image, and the features of each image are listed in Table II. Table III shows that the average PSNR depends on the input image.

On average, the proposed method has a high PSNR compared with each method. Since the modified ELA method using the Profile Pattern is superior to the GA de-interlacer in terms of edge processing performance, the modified ELA method had a higher PSNR for input images with many edge elements. For general images, the GA de-interlacer using a median filter had a high PSNR. Since the proposed method uses EMF as a spatial filter, it had a relatively high PSNR for all input images.

However, it is difficult to measure the performance of a de-interlacer using the PSNR. Missing motion or false motion may cause a rapid deterioration in picture quality, even with a relatively high PSNR. Since a GA de-interlacer uses a simple line average as a spatial filter and cannot properly detect movement compared with the proposed method, this problem frequently occurs with a GA de-interlacer. For images containing relatively fast motion, missing-motion error occurs and the interpolation is performed incorrectly. Figure 8 shows part of the image of a flower garden, which contains much movement as a whole. All of this part of the image is considered moving and there are edges oriented in various directions that cause problems when extracting the edge map. Fig. 9 shows an area of dense line edges.

As shown in the figure, the GA de-interlacer (b) and modified ELA (c) interpolate pixels incorrectly. The proposed method (d) prevents this incorrect interpolation of pixels by extracting the exact edge map and applying a median filter.

TABLE III
AVERAGE PSNR FOR TEST IMAGES

Method	Susie	Table Tennis	Football	Flower Garden	Pop
Line doubling	30.19	23.50	25.53	17.99	23.52
Line average	34.47	25.47	28.35	20.08	26.00
GA HDTV de-interlacer	40.36	33.14	33.58	26.29	35.42
Modified ELA using a profile pattern	35.09	32.28	34.99	29.24	32.10
Proposed method	41.31	34.29	35.13	30.36	35.82

Fig. 10 shows an area of the football image with rapidly changing movement. The GA de-interlacer (b) produces rapid deterioration of the picture quality at the edge. The restored image using a modified ELA filter is shown in (c). Since the latter method calculates the average by extracting the edge map, image (c) resembles the original image and shows the part interpolated with the wrong pixel value. It is clear that the proposed method (d) performs best.

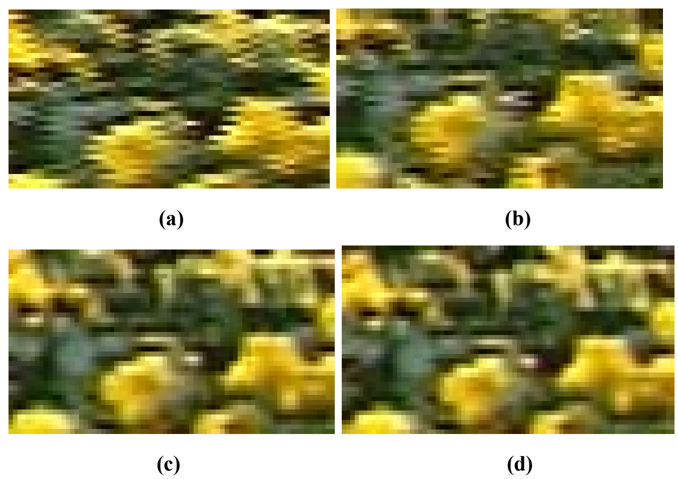


Fig. 8. Interpolation for moving region: (a) Original interlaced image, (b) GA de-interlacer, (c) Modified ELA, and (d) Proposed method

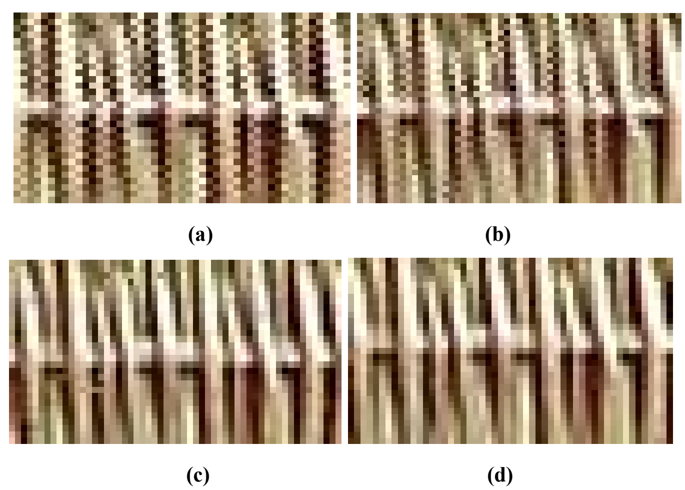
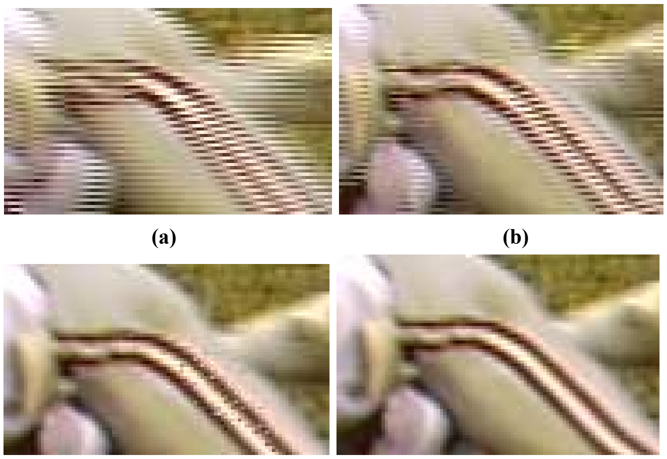


Fig. 9. Interpolation of a thin edge line pattern: (a) Original interlaced image, (b)GA de-interlacer, (c) Modified ELA, and (d) Proposed method



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

Fig. 10. Interpolation for a fast moving region: (a) Original interlaced image, (b)GA de-interlacer, (c) Modified ELA, and (d) Proposed method

V. CONCLUSION

This paper presents a de-interlacing method that uses two interpolation methods. It enables effective interpolation by using an edge-based median filter (EMF) to remove false motion error and detect moving diagonal edges by acting as a spatial filter. This paper also presented an adaptive maximum pixel difference filter (AMPDF) that determines more exact pixel values via 3-step exploration by subdividing the input images into areas with movement, background, and boundary areas, and establishing different threshold values for each. The results of a computer simulation showed that our method eliminates all the problems with existing methods and performs better.

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REFERENCES

[1] G. D. Haan and E. B. Bellers, "De-interlacing – An overview," *Proceedings of IEEE*, vol. 86, no. 3, pp. 1839 – 1857, Aug. 1998

[2] T. Chen, H. R. Wu, and Z. H. Yu, "An efficient edge line average interpolation algorithm for de-interlacing," *Visual Communications and Image Processing 2000, Proceedings of SPIE*, pp. 1551-1558, Oct. 2000

[3] C. J. Kuo, C. Liao, and C. C. Lin, "Adaptive interpolation technique for scanning rate conversion," *IEEE Trans, Circuits Syst. Video Technol.*, vol. 6, no. 3, pp. 317 –321, Jun. 1996

[4] D. Hargreaves and J. Vaisey, "Baysian motion estimation and interpolation in the interlaced video sequence," *IEEE Trans. Image Processing*, vol. 6, no. 5, pp. 764-769, Oct. 1997

[5] R. Li, B. Zeng, and M. L. Liou, "Reliable motion detection/compensation for interlaced sequence and its applications to deinterlacing," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 10, no. 1, pp. 23-29, Feb. 2000

[6] D. Han, C. Shin, S. Choi, and J. Park, "A motion adaptive 3-D de-interlacing algorithm based on the brightness profile pattern difference," *IEEE Trans. Consumer Electronics*, vol. 45, no. 3, pp. 690-697, Aug. 1999

[7] B. Bhatt, F. Templin, B. Hogstrom, H. Derovanessian, S. Lamadrid, and J. Mailhot, "Grand Alliance HDTV multi-format scan converter," *IEEE Trans. Consumer Electronics*, vol. 41, no. 3, pp. 1020-1031, Aug. 1995

[8] M. Lee, J. Kim, J. Lee, K. Ryu, and D. Song, "A new algorithm for interlaced-to-progressive scan conversion based on directional correlations and its IC design," *IEEE Trans. Consumer Electronics*, vol. 40, no. 3, pp. 119-129, Aug. 1994

[9] Y. Kim and Y. Cho, "Motion adaptive de-interlacing algorithm based on wide vector correlations and edge dependent motion switching," *HDTV Workshop 95*, pp. 8B9-8B16, Oct. 1995

[10] G. D. Haan and E. B. Bellers, "De-interlacing of video data," *IEEE Trans, Consumer Electronics*, vol. 43, no. 3, pp. 819-825, Aug. 1997

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