UACEE International Journal of Computer Science and its Applications - Volume 2: Issue 3 [ISSN 2250 - 3765]

Evaluation of De-Interlacing Techniques for 1080i HDTV

Muhammad Yaqoob
Department Of Computer Engineering
University of Engineering and Technology Taxila
Rawalpindi, Pakistan
muhammadyaqoob44@gmail.com

Khalid Bashir Bajwa
Department Of Telecommunication Engineering
University of Engineering and Technology Taxila
Rawalpindi, Pakistan
khalid.bashir@uettaxila.edu.pk

***Abstract*— The paper presents the evaluation and grading of different techniques that are in use today for the de-interlacing of High Definition interlaced content. S2 (1080i/25) is one of the standards for High Definition Television (HDTV) that is broadcasted in Europe, USA and other parts of world. Different de-interlacing techniques starting from basic ones like line averaging, field insertion to advanced ones like motion adaptive and motion compensation are reviewed. These techniques are evaluated using objective video quality metrics like Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE) and more advanced one like Structural Similarity (SSIM). Subjective evaluation is carried out using perception based subjective video quality metric (Mean Opinion Score). The comparison of subjective and objective results shows that there is a high correlation among the subjective scores and the objective criterion.**

Keywords—1080i HDTV, De-interlacing, Objective Assessment, Video quality.

I. Introduction

High Definition Television (HDTV) is becoming more and more popular due to its high quality content and better picture quality. The television industry is already into transition phase migrating towards high definition channels and better quality broadcasting content. Interlaced scan has always been an important aspect of broadcasted television, and is used today in HDTV standard S2 as 1080i/25 because of its data rate.

The specifications for the basic image formats and digital sampling systems of HDTV production in the European 50 Hz environment are described in [1]. It is intended to meet the demands of European Broadcasting Union (EBU) Members for interoperability and implementation stability in their HDTV production systems. Four HDTV production systems are recognized for use in Europe [1].

Interlaced video consists of two fields that are captured after one another in sequence at odd and even lines of the image sensor respectively. This technique was conventionally used in analog displays. By making use of understanding of the human perception, interlacing enabled systems to use less bandwidth to display the video and image sequences with the same perceived quality as that of progressive sequences. Due to analog nature Cathode Ray Tube (CRT) based displays are capable of displaying interlaced content correctly. On the other hand modern displays are inherently digital and are migrating from CRT's to LED's (Light Emitting Diode), TFT, plasma and other technologies. Due to this reason, the two sub-fields need to be combined to form a single frame that results in various visual defects and artifacts. De-interlacing process should try to remove or minimize these artifacts. In past, many de-interlacing techniques were proposed and new methods are still being proposed.

De-interlacing can be categorized into spatial methods and temporal methods depending upon the use of current field or previous fields for interpolation. The former includes techniques such as line filtering, line based averaging, edge based line averaging and edge based weighted median filtering. The later includes inter field line averaging, vertical-temporal filtering, vertical-temporal median filtering. By making use of objective metrics such as Motion Trajectory In- consistency (MTI) and Mean Square Error (MSE) various de-interlacing algorithms evolved in past, but still the relation between objective metrics and perceived video quality of image sequences remains unclear. Our focus is to evaluate different techniques using conventional and modern metrics not only objectively but also to evaluate them subjectively with the use of Mean Opinion Score (MOS). We discover the connection between the subjective scores and objective criterion. This assessment will disclose the dependability of the objective metrics like MSE and Peak Signal to Noise ratio (PSNR).

The paper is structured in the following way. Section 2 gives the review of different de-interlacing techniques. Section 3 describes the evaluation procedure of various de-interlacing algorithms. The results of evaluation and discussion about them are presented in Section 4. The paper concludes in Section 5.

II. Review Of Evaluated De-interlacing Techniques

A. *Line Repetition*

Line repetition is the straightforward process which uses the data from above line to fill up missing line pixels [2]. It is defined as

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ f\left(\vec{x} - \binom{0}{1}, n\right) & else \end{cases} \quad (1)$$

where $f_{out}(\vec{x},n)$ is the de-interlaced output frame, $\vec{x} = (x,y)^t$ is the spatial point while t is the transpose. The $f(\vec{x},n)$ represents input field. Also $\left(\vec{x} - \binom{0}{1}\right)$ is equivalent to *(x-0)(y-1)*. It is the pixel exactly above the missing pixel. '*n*' is the field number and is odd when field is captured at odd lines and vice versa. It can be observed that y mod 2 == n mod 2 is true for even rows in even fields and odd rows in odd fields. These rows are called original lines in de-interlaced frame. Output lines resulting from calculation are called interpolated lines.

B. Line Averaging (Line Filtering)

Line averaging filter interpolates the missing pixel by averaging the pixels vertically above and below the missing pixel [2]. It is stated as

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ \frac{f(\vec{x}-\binom{0}{1},n)+f(\vec{x}+\binom{0}{1},n)}{2} & else \end{cases} \qquad (2)$$

Where $\left(\vec{x}-\binom{0}{1}\right)$, $\left(\vec{x}+\binom{0}{1}\right)$ are the pixels above and below the missing pixel. With a larger vertical filter the impulse response defined as:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ \sum f\left(\vec{x}+\binom{0}{k},n\right), h(k) & else \\ (k \in \{..,-1,0,1,2,..\}) & \end{cases} \qquad (3)$$

with $\sum$ giving us the sum of pixels vertically above and below the missing pixel and *h(k)* providing the averaging factor.

C. Inter-field line averaging

Instead of performing average on vertical lines, it can also be done on the two consecutive fields in time [3]. The output is calculated as:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ \frac{f(\vec{x},n-1)+f(\vec{x},n+1)}{2} & else \end{cases} \qquad (4)$$

with *(x,n -- 1)* is *(x,y)* pixel of *(n – 1)* (previous) field and vice versa.

D. Vertical-Temporal filtering

Linear vertical-temporal filtering is used for de-interlacing purposes by using previous or next fields as input [3]. It is defined as:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ \sum_{k,j} f\left(\vec{x}-\binom{0}{2k},n-j\right), h(k) & else \\ (k \in \{..,-1,0,1,2,..\}) & \end{cases} \qquad (5)$$

with $k = -L....0...\ L$ and vertical filter length of $2L+1$ taps, j=-J..,-1,0,1,..J and J as the number of previous fields involved in calculation. As the cost for memories required for fields are still on the higher side, j is restricted to a small number.

E. Vertical-Temporal Median filtering.

Median filters that are from the class of order statistical filters are often used in image processing. It has proved to be an effective method to perform de-interlacing [4]. Three-tap vertical temporal median filter is the most encountered variety of it [5] and is shown in Fig. 1.

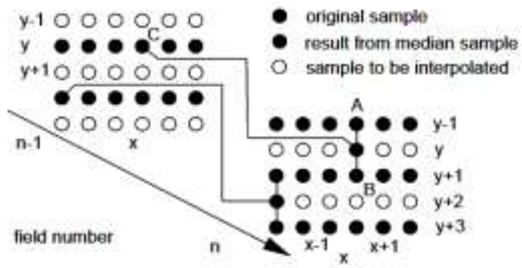


Fig. 1. Vertical-temporal median filtering

The interpolated pixel value is calculated by performing median filtering on the vertical spatial neighbors and the equivalent sample in the previous field:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), \ y \bmod 2 == n \bmod 2 & \\ median\begin{cases} f\left(\vec{x}-\binom{0}{1},n\right) \\ f\left(\vec{x}+\binom{0}{1},n\right) \\ f(\vec{x},n-1) \end{cases} & else \end{cases} \qquad (6)$$

F. Edge Based Line Average

In Edge Based Line Average (ELA) algorithm direction with the maximum sample correlation is determined and then interpolation is done within its neighborhood based on the found directional correlation [6], [14]. It is a sort of spatial filter and shows reasonably fine performance in motion areas. Yet its implementation is quite simple. A 3 x 2 window is used which is in shown Fig. 2. It detects negative diagonal, vertical and positive diagonal directional correlations. Based on the highest correlation, interpolation direction is determined.

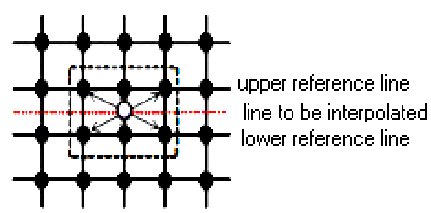


Fig. 2. 3x2 Window used for Directional Correlation

Directional correlation (*C(k)*) in ELA is defined as (7).

$$C(k) = \left(|f'(x-1,y+k) - f'(x+1,y-k)|\right) \qquad (7)$$

$$k = -1, 0, 1$$

Edge direction is given as

$$\theta = argmin_k C(k), \quad where -1 \le k \le 1 \qquad (8)$$

f'(x -- 1,y) , *f' (x+1,y)* are upper and lower pixel lines for that odd or even field.

Missing pixel will be calculated as

$$f_{out}(x,y) = \frac{f'(x-1,y+\theta)+f'(x+1,y-\theta)}{2} \quad (9)$$

ELA uses inaccurate edge information when angle of the direction is not 45 degrees. This flaw has been minimized by E-ELA algorithm with the help of more direction determination conditions. But still the limitation on window size degrades the image quality even for smooth slopes.

G. Edge Based Weighted Median Filter

This filter addresses the problem of ELA algorithm and performs interpolation that reduces the degradations faced in ELA [7]. It has two key steps [8], first one Edge Direction Detection and the second one is Edge Direction Refinement, as shown in block diagram in Fig. 3. Edge-direction information map helps in finding edge direction within neighborhood. Seven absolute differences are computed along the seven likely edge directions to finalize edge-direction information map as shown in Fig. 4. Edge direction enhancement is performed to improve primary edge direction information with the help of 13-tap weighted median filter.

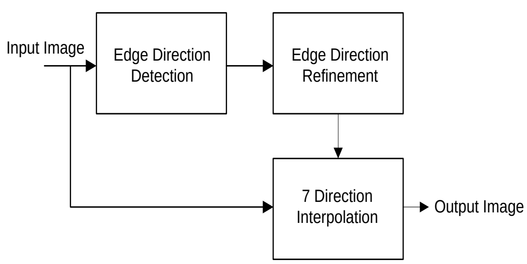


Fig. 3. Block Diagram of Edge Based Weighted Median Filter

1) Edge Direction Detection filter

Edge information for each pixel of input field is determined by an edge direction detection filter.

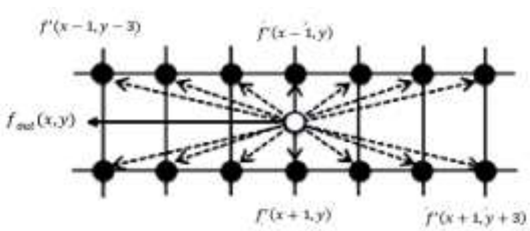


Fig. 4. Seven possible edge directions

Here $f_{out}(x,y)$ is the pixel that is to be interpolated. Its edge direction information is given as (10).

$$\theta_{(x,y)} = argmin_k(|f'(x-1,y+k) - f'(x+1,y-k)|) \quad (10)$$

Where $k = -3,-2,-1,0,1,2,3$

2) Edge Direction Refinement using WMF

A Weighted Median filter is used to get the median value in a window having odd number of samples. The filter is defined as shown in Fig. 5.

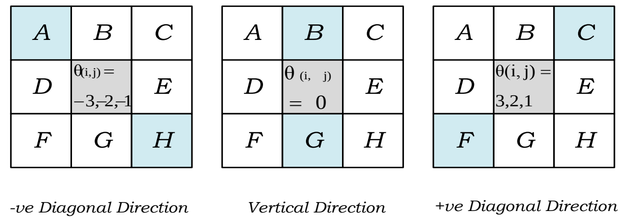


Fig. 5. 3x3 masks for 13-tap weighted median filter

By applying 3x3 weighted median mask on the edge direction information the final interpolated edge direction is obtained. Three different ways are used for it on the basis of edge information as given in [8].

Refined directions are then used to calculate the missing pixel value as given by (11).

$$f_{out}(x,y) = \frac{f'(x-1,y+\theta')+f'(x+1,y-\theta')}{2} \quad (11)$$

H. Motion-Adaptive De-interlacing using Hybrid Motion Detection

This de-interlacing makes use of the motion detection, and switches between filtering techniques corresponding to motion and non-motion sequences by making use of luminance differences between numerous successive fields. In motion-adaptive de-interlacing [9], inter-field technique is used for interpolation for stationary scenes and intra field approach is chosen for motion cases. Correctness of motion information strongly affects the visual quality of these methods.

The latest proposed motion adaptive algorithm, shown in Fig. 6 below, is made up of a motion detector unit and a pixel interpolator [10]. Motion detector performs hybrid motion detection (HMD) and has a refinement unit. Hybrid motion detector makes use of the pixel information of three fields only. The interpolator consists of edge pattern recognition (EPR) unit and field insertion (FI) unit. EPR is used when a pixel is detected to have motion, and FI is used for alternative case. HMD and EPR are devised to attain high flexibility towards a diversity of motion, edges and textures.

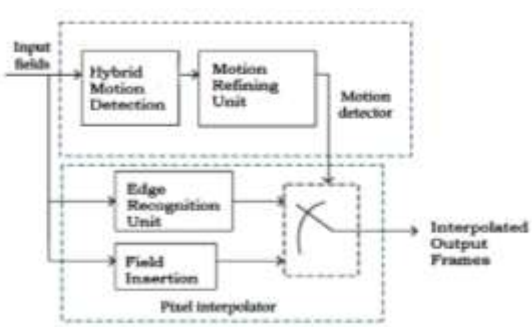


Fig. 6. Motion adaptive with HDM algorithm

1) Motion Detection

Motion detection is usually done on the basis of field difference [11]. The presence of motion is detected using the data of three fields. If the motion is detected the intra field interpolation is used. The three conditions for detection of motion and the pseudo codes are stated in [10].

HMD merges the advantages of 2- field motion detection and 3- field motion detection. 3-field motion detection has better tendency to detect static pixels accurately, while 2-field motion detection approach can detect very fast motions that are not distinguished by 3-field motion detection. The last condition adds to the detection accuracy of edges.

2) Pixel Interpolation

EPR is used for motion containing scenes while FI is used for static scenes. HMD adaptively selects inter-field or intra-field approaches to calculate the output. We have used ELA algorithm for EPR and simple field insertion otherwise.

I. Motion Compensated De-interlacing

Motion-adaptive methods distinguish only between motion and no motion. Information about speed and direction of motion is neither generated nor is it used for interpolation [12]. True motion compensation, however, derives this information and uses it to preserve vertical resolution, even in moving objects. Motion compensated algorithms perform interpolation in the direction having the maximum correlation [13], [17]. Motion vectors do not describe all temporal information changes. Obscured backgrounds, scene changes and fades are several difficulties faced.

In following is the brief description of couple of motion compensation techniques that are used for de-interlacing.

1) MC Median filtering

As described previously, vertical-temporal median filtering carries out line repetition in the presence of motion. But when the motion vectors are identified, the correlation can be improved by changing the current spatial sample position over the motion vector in the previous field. It is shown in Fig 7.

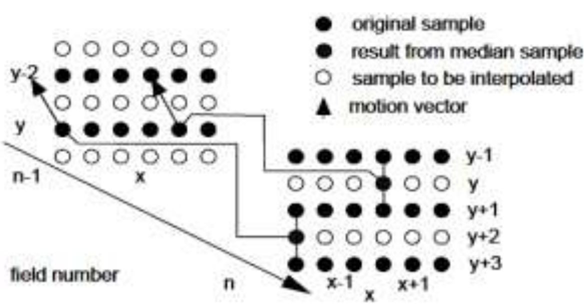


Fig. 7. Motion Compensated median filtering.

With *d(x,n)* as precise motion vector at position *x* in the field , the output is given as:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ median\begin{cases} f(\vec{x}-\binom{0}{1},n) \\ f(\vec{x}+\binom{0}{1},n) \\ f(\vec{x}-\vec{d}(\vec{x},n),n-1) \end{cases} & else \end{cases} \quad (12)$$

2) MC Time Recursive De-interlacing

In MC Time-Recursive (TR) de-interlacing, interpolation is done by applying motion compensation using the previously de-interlaced field [13]. It is stated as:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ f_{out}(\vec{x}-\vec{d}(\vec{x},n),n-1) & else \end{cases} \quad (13)$$

Missing rows of the current filed are calculated with the help of standard sample rate conversion theory after getting perfectly de-interlaced previous frame and accurate motion vectors. However, it has been observed that de-interlacing and motion vectors are not found to be perfect. As the samples interpolated for the current frame are based on samples interpolated of the previous field, errors originating in one frame can propagate into later output frames. To avert these errors from propagating, several solutions have been illustrated in [15]. Predominantly, the median filter is suggested to solve this issue. We can say that the TR de-interlacing method is very much alike the motion compensated median filter approach, but differs from it in the way that the previous image in TR method consists of previously de-interlaced field instead of the previous field. The output is defined as:

$$f_{out}(\vec{x},n) = \begin{cases} f(\vec{x},n), & y \bmod 2 == n \bmod 2 \\ med\begin{cases} f(\vec{x}-\binom{0}{1},n) \\ f(\vec{x}+\binom{0}{1},n) \\ f_{out}(\vec{x}-\vec{d}(\vec{x},n),n-1) \end{cases} & else \end{cases} \quad (14)$$

This method produces far better results however median filter may introduce aliasing in the output de-interlaced frame.

The fact is that due to their inertia, objects always take time to change their geometry or completely disappear from the frame, therefore, a strong correlation of successive images always exists which makes motion compensated de-interlacing methods the strongest one.

III. Evaluation

The sequences used in the evaluation are Beckham having high details and slow velocities from left to right , Eifel Tower having slow zoom and ample vertical edges , Crowd having a lot of details and critical velocities, Jogging sequence with movement , motion and zoom out camera angle, Boxing with close view and rapidly changing scenario , Ice Dance with fast camera movement and high vertical and horizontal velocities, and Circle, a static sequence, having many vertical and horizontal edges. All these sequences are 1920x1080 according to 1080i HDTV standard.

A. Objective Evaluation

We used SSIM, PSNR and MSE for the objective evaluation of the algorithms. PSNR metric is most highly rated objective quality metric along with the MSE [16]. However, the non-linear conduct of the human visual system strongly affects the relation between PSNR values and perceived visual quality. Structural similarity (SSIM) index is intended to give better results in comparison to traditional methods due to inconsistency of these methods with human eye perception. SSIM index gives information about the level of similarity between the two images. It is a full reference metric. The resultant values of SSIM range between -1 and 1.

B. Subjective Evaluation

As MSE and PSNR measures are global, local disturbances which are very annoying to the human observer are not given significant weight in the measure [19]. The goal of our evaluation is to measure how satisfied the human visual system is with different de-interlacing results and thus subjective evaluation is performed. A paired comparison of output sequences was carried out for subjective evaluation. Peak luminance on the screen was set at 200 (cd/m^2) as stated in ITU-R BT.710-4 [18]. Illumination from other sources was set low. Observers were arranged with in ± 30° horizontally from the centre of the display and at a distance of 5 feet from the display screen. Observers can rate the sequences from 1(worst) to 10(best). The initial sequences are included to show the relative quality of the different algorithms. The MOS was calculated with the arithmetic mean of all the individual scores.

IV. RESULTS

The results for both of the evaluations are shown below where table 1 gives the PSNR scores of the sequences and table 2 shows the SSIM index values for sequences calculated locally on blocks of 16x16 size. Subjective scores in form of average MOS values for test sequences are shown in table 3. Interlaced images were shown to 15 viewers and rating was done ranging from 1 as worst to 10 as best. The correlation factor was found to be 0.691 between MOS and PSNR, and 0.754 between MOS and SSIM. The comparison of MOS scores with both of objective criterions was performed. Relationship between subjective MOS scores and objective PSNR scores is presented in Fig.8. (a) and that of MOS with SSIM scores is shown in Fig. 8 (b).

TABLE I. PSNR SCORES OF THE EVALUATED TEST SEQUENCES

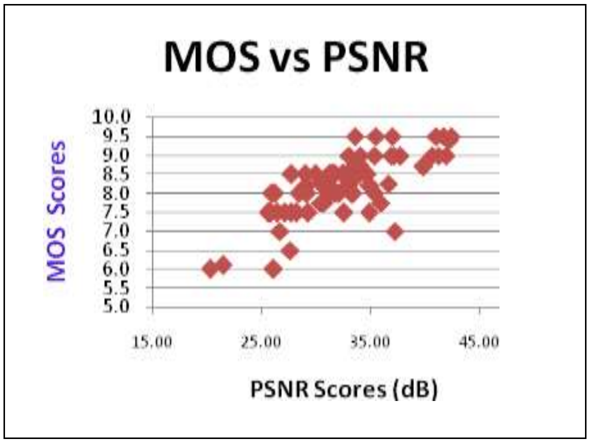
Image	Line Repetition	Line Averaging	Inter-field line Averaging	Vertical-Temporal filtering	Vertical-Temporal median filtering	Edge Based Line Average	Edge Based WM F	Motion-Adaptive De-interlacing	MC Median filtering	MC Time Recursive filtering
Boxing	28.95	33.98	35.31	31.42	41.90	32.04	31.68	41.73	42.15	42.36
Crowd	33.30	37.66	21.41	33.49	39.80	33.92	32.86	40.60	40.99	41.19
Beckham	30.41	31.49	26.07	29.23	32.87	30.64	28.33	33.53	34.86	34.03
Circle	34.69	34.81	29.90	32.97	35.87	33.22	32.52	36.58	36.94	37.12
Ice Dance	32.47	31.25	25.97	28.17	32.34	29.12	27.72	32.99	33.31	35.47
Jogging	25.65	27.74	37.16	26.68	30.34	25.53	25.79	30.95	31.25	31.41
Eifel Tower	27.14	29.13	20.21	27.60	31.72	26.41	26.15	35.35	37.67	36.83

TABLE II. SSIM (LOCAL) SCORES FOR THE EVALUATED TEST SEQUENCES (-1 WORST, 1 BEST MATCH)

Image	Line Repetition	Line Averaging	Inter-field line Averaging	Vertical-Temporal filtering	Vertical-Temporal median filtering	Edge Based Line Average	Edge Based WM F	Motion-Adaptive De-interlacing	MC Median filtering	MC Time Recursive filtering
Boxing	0.947	0.973	0.986	0.964	0.992	0.965	0.967	0.994	0.994	0.995
Crowd	0.955	0.980	0.599	0.976	0.991	0.971	0.974	0.993	0.993	0.994
Beckham	0.946	0.968	0.860	0.972	0.979	0.964	0.963	0.981	0.982	0.982
Circle	0.940	0.960	0.897	0.962	0.976	0.953	0.954	0.978	0.978	0.979
Ice Dance	0.956	0.973	0.848	0.964	0.989	0.967	0.968	0.991	0.991	0.992
Jogging	0.827	0.898	0.980	0.882	0.954	0.846	0.865	0.956	0.957	0.957
Eifel Tower	0.893	0.933	0.646	0.932	0.967	0.906	0.911	0.969	0.969	0.970

TABLE III. AVERAGE MOS SCORES FOR THE EVALUATED TEST SEQUENCES – (15 VIEWERS) (0-TO-10)

Image	Line Repetition	Line Averaging	Inter-field line Averaging	Vertical-Temporal filtering	Vertical-Temporal median filtering	Edge Based Line Average	Edge Based WM F	Motion-Adaptive De-interlacing	MC Median filtering	MC Time Recursive filtering
Boxing	8.5	8.8	8.0	8.1	9.0	8.0	8.5	9.5	9.4	9.5
Crowd	8.0	9.0	6.1	8.5	8.7	8.5	8.5	9.0	9.5	9.0
Beckham	7.8	8.5	6.0	7.5	8.5	7.8	8.0	9.5	8.2	9.0
Circle	8.5	7.5	8.5	8.3	7.8	8.0	7.5	8.3	9.5	9.0
Ice Dance	8.5	8.5	8.0	7.5	8.5	8.0	8.5	9.0	8.0	9.5
Jogging	7.5	7.5	7.0	7.0	8.3	7.5	7.5	8.3	8.0	8.5
Eifel Tower	7.5	8.2	6.0	6.5	8.0	7.5	8.0	9.0	9.0	9.0



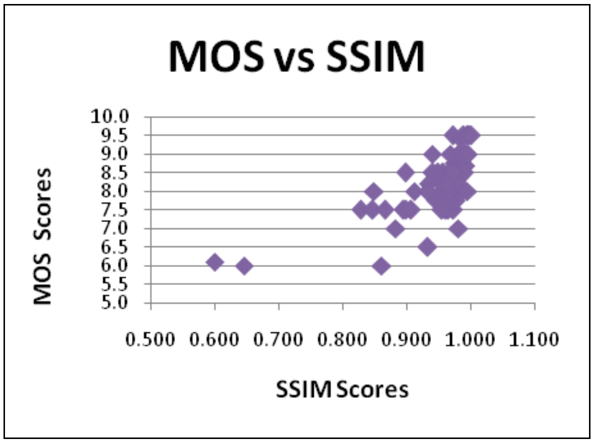


Fig. 8. Comparison of MOS with a) PSNR (dB) b) SSIM

V. Conclusion

Different de-interlacing techniques have been assessed in this paper. The results show that the motion compensated methods are generally better for moving videos than the other methods. The MC median filtering does better than the other de-interlacing methods. A single sequence was found with better result with alternative method. For sequences with complex motion but without vertical frequencies the motion compensated methods are found to be better than the other methods. It is also observed that the TR method has small edge over MC median filtering for objective scores of the evaluated sequences. One place where TR produces better results is for the sequences with vertical velocities, since TR algorithm make better use of interpolation filters with the help of de-interlaced field then the MC median filtering. This is fairly authenticated in the assessment.

It can be seen from the graph in figure 10 that PSNR scores are generally on the higher side when MOS scores are higher but they do not show exact linear behavior with respect to MOS scores. But in figure 11 we can see that SSIM scores are pretty much higher for high MOS scores and show better linear relation with MOS scores than PSNR. Hence, SSIM objective metric is highly correlated with subjective criterion and give us scores that show better perception measures as also been shown by correlation factor.

References

[1] “HD Image Formats for TV Production, “EBU – TECHNICAL -3299, Geneva, January 2010.

[2] de Haan, Gerard and Bellers, Erwin, “ Deinterlacing – An Overview,” Proceedings of the IEEE, Vol. 86, No. 9, Sept 1998.

[3] M.J. Chen, C.H. Huang, and C.T. Hsu,” Efficient De-interlacing Technique by Inter-Field information,” IEEE Transactions on Consumer Electronics, 50(4):1202 – 1208, Nov 2004.

[4] M.J.J.C. Annegarn, T. Doyle, P.H. Frencken, and D.A. van Hees, “Video signal processing circuit for processing an interlaced video signal,” European Patent Application no. EP-A 0 192 292.

[5] Phu, M. Q. ; Tischer, P.E. ; Wu, H. R, "A median based interpolation algorithm for de-interlacing" , ISPACS 2004. Proceedings of International Symposium on, pp. 390 - 397, Nov. 2004.

[6] Y.-L. Chang, S.-F. Lin, and L.-G. Chen , Extended Intelligent edge-based line average with its implementation and test method,” in Proceeding of the IEEE International Symposium on Circuits and Systems (ISCAS ’04), vol. 2, pp. 341–344, Canada, May 2004.

[7] H.S. Oh, Y. Kim, Y. Jung, A. W. Morales, and S.J. Ko.” Spatio-Temporal Edge-based Median Filtering for De-interlacing,” Digest of Technical Papers, International Conference on Consumer Electronics, pages 52 – 53, Jun 2000.

[8] Seung-Min Jang, Ju-Hyun Park, Sung-Hoon Hon,” De-interlacing method based on edge direction refinement using weighted median filter,” IEEE International Conference on Signal and Image Processing Applications, 2009.

[9] S.-F.Lin, Y.-L.Chang, and L.-G. Chen,” Motion adaptive interpolation with horizontal motion detection for de-interlacing,” IEEE Transactions on Consumer Electronics, vol. 49, no. 4, pp. 1256-1265, 2003.

[10] Gwo Giun Lee, Ming-Jiun Wang, Hsin-Te Li,” Adaptive De-interlacer via Hybrid Motion Detection and Edge-Pattern Recognition”, EURASIP journal on Image and Video Processing, Vol. 2008, Article ID 741290.

[11] C.L. Lee, S. Chang, and C.W. Jen, “ Motion Detection and Motion Adaptive pro-scan conversion,” IEEE International Symposium on Circuits and Systems, volume 1, pages 666 – 669, June 1991.

[12] S. Yang, Y.Y. Jung, Y.H. Lee, and R.H. Park. “ Motion Compensation assisted Motion Adaptive interlaced-to-progressive conversion,” IEEE Trans. Circuits Syst. Video Techn., 14(9):1138–1148, 2004.

[13] X. Gao, J. Gu and J. Li, “De-interlacing Algorithms Based on Motion Compensation,” IEEE Trans. Consumer Electronics. vol. 51, no. 2, pp. 589-599, May. 2005.

[14] T. Doyle and M. Looymans, “ Progressive scan conversion using edge information,” Signal Processing of HDTV II, pages 711–721, 1990.

[15] F.M. Wang, D. Anastassiou, and A.N. Netravali, “Time-Recursive De-interlacing for IDTV and Pyramid Coding,” in Signal processing: Image Communications .Elsevier.

[16] Nicolas,Rousseland Crete, “ Metrics to Evaluate The Quality of Motion Compensation Systems in De-interlacing And Up-conversion Applications,” International Conference on Consumer Electronics, pp. 1-2 , Jan 2008.

[17] H. Yoo and J. Jeong. “ Direction-oriented Interpolation and its Application to De-interlacing,” IEEE Transactions on Consumer Electronics, 48(4):954 – 962, 2002.

[18] Recommendation ITU-R BT.710-4, “Subjective assessment methods for image quality in High-Definition Television,” .

[19] Hoffmann, H.,Itagaki,Wood, D.,Hinz, T.Wiegand,T, "A Novel Method for Subjective Picture Quality Assessment and Further Studies of HDTV Formats,"IEEE Transactions On Broadcasting, VOL. 54, NO. 1, March 2008.