Progressive versus Interlaced Coding

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Abstract

Interlaced versus progressive scanning is an important issue when dealing with digital television. Not only because the change from analog to digital communication may be seen as an opportunity to move to other formats, but also because of the well-known artifacts of interlaced scanning (interline twitter, line crawling, and field aliasing) compared to the natural way of representing two-dimensional images as the progressive format does. However, digital broadcasting has to face the problem of transmitting twice the number of pels of the progressive format. It is the purpose of this article to study this problem, and especially to check if the increased vertical and temporal correlations of the progressive pictures provide a significant improvement in the bit-rate reduction efficiency. In that case, progressive scanning may also be used as an intermediate transmission format to improve the compression performances of interlaced sequences.

1. Introduction

Interlaced scanning was introduced about 25 years ago as a simple and effective trick to halve the bandwidth, resulting in a shape size in the vertical/temporal domain adapted to the human vision limitations, hence its high spatial definition and field rate. However, critical material emphasizes typical interlaced artifacts, such as the well-known interline twitter, line crawling and field aliasing[1]. These defects are much more annoying today because of the improved picture quality of both displays and cameras. Moreover, half the bandwidth for analog transmission of TV signals is an efficient solution, whereas for digital communication the challenge lies in achieving a high picture quality at a given bit rate. This requirement in the coding efficiency leads to the MPEG-2 standard [2].
From these considerations progressive scanning can be considered as a candidate for a new transmission format, because progressive pictures have higher vertical resolution, seem much more attractive than interlace for signal processing, and guarantee the compatibility with other multimedia applications. Unfortunately, the number of samples is twice that of the existing interlaced format.

It is the purpose of this paper to compare the efficiency of both progressive and interlaced formats in the context of a MPEG-2 coding scheme. Based on these results different conclusions will be drawn to demonstrate that the progressive format improves the overall picture quality, and that such a transmission format may be also an intermediate step towards progressive broadcasting without loss of performances compared to the existing interlaced one. Unfortunately the compression performances can not be significantly increased.

2. Coding Efficiency Comparisons

The included simulation results are obtained from two different MPEG-2 broadcasting chains in both scanning formats (details in [3]), and with the following source materials (results for the four last progressive sequences are available only with interlaced display) :

• **Interlaced :** *Mobile and Calendar* and *Flower and Garden :* From a tube camera*;*

• **Progressive :**

Renata RAI : From an HDTV tube camera;
Kiel Harbor and *Kiel Harbor 2* : Digitized photo with synthetic motion;
Pendel and *Foot* : From a progressive tube camera;
Pops : From a progressive CCD camera;

Two different deinterlacers, one at the transmitter side (high quality motion compensated [4]), one at the receiver side (low cost macroblock based solution, making use of the transmitted MPEG-2 motion vectors), deal with the interlaced to progressive conversions (more details can be found in [5]). The opposite format changes are performed through vertical filtering (including the Kell factor) and subsampling.
In addition, two bit-rates have been selected (4 Mbit/s excepted *MOBILE* encoded at 6 Mbit/s) in order that the picture quality over all the set of sequences is constant (PSNR between 30 and 35 dB). The PSNR (Peak Signal to Noise Ratio) together with a subjective expert analysis evaluate the efficiency of each scenario.

2.1 MPEG-2 Encoding Parameters

Some parameters have to be defined to comply with the MPEG-2 syntax. Among them some are specific to the progressive format and can be optimized such as :

- *progressive_frame* set to 1, coded video contains only progressive frame pictures. It leads to : *picture_structure*= "frame" and *frame_pred_frame_dct*=1;
- *frame_pred_frame_dct* set to 1. For each macroblock, this flag suppresses useless flags like *frame_motion_type* (2 bits) and *dct_type* (1 bit) from the bitstream;
- The motion estimator is a 5 hierarchical levels block-matching with a [-127,+128]×[-63,+64] half-pel vector range. It is based on a pyramidal structure which leads to a very simplified and efficient data processing when dealing with progressive (1 vector instead of 5). Furthermore, it leads to a simplified mode decision processor.

Accordingly, progressive coding reduces the side-information by 3 bits/macroblock, it lowers the number of vectors to transmit, and simplifies the chrominance filters.
Other MPEG-2 parameters are identical for both formats such as the VLC intra tables *(intra_vlc_format=1*), the non-intra quantization matrix (flat), the macroblock mode selection, the thresholding of the DCT coefficients, the quantizer type (*q_scale_type*=0), the zig-zag matrix (*alternate_scan*=0). All these points are not in the scope of this paper and will not be further discussed.
The encoder is thus MPEG-2 compliant except for its use of the progressive (not currently supported by this profile). Anyway, the objective of this study is to compare both formats with the same picture size, and a new level might be further included in the MPEG-2 final standard specification to comply with progressive scanning.

Finally, only the GOP structure remains to be specified. For interlaced signals the classical one is used (M=3, N=12) when for progressive pictures computer simulations lead to M=5, N=25 (slightly more efficient than M=6, N=24).

2.2 PSNR and subjective picture evaluation

Let us just remind that between pictures of the same format a better PSNR value generally means a better picture quality if the gap is significant (greater than 0.5 dB), otherwise subjective picture evaluation is required. For instance with the previous display formats, and considering that progressive display leads to a higher picture quality, a lower progressive PSNR value does not necessarily mean a lower picture quality.

• **Interlaced display** (progressive coding + receiver interlacing / interlaced coding + display) **:**

	Mobile		**Flower**		**Kiel**		**Renata**	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	29.32	32.30	30.38	30.64	32.11	31.61	33.49	33.14
PSNR (dB) U	33.90	34.45	33.47	33.39	39.08	39.23	36.07	35.69
PSNR (dB) V	31.85	32.11	31.87	31.38	37.82	38.00	37.86	37.67
	Foot		**Kiel 2**		**Pendel**		**Pops**	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	32.23	30.84	29.17	27.81	41.25	41.87	36.35	36.99

Table 1 - PSNR (dB) for interlaced signals

Progressive coding performs slightly better (PSNR and picture quality) for 4 sequences (*Kiel, Renata, Foot, Kiel 2*). For two (*Flower* and *Pendel*) the visual quality is in favor of the progressive format, confirming that the PSNR difference is too low to be significant (*Flower* < 0.3 dB), or too high for visual artifacts (*Pendel*). And finally, *Pops* leads to visually similar pictures (difference = 0.6 dB), and *Mobile* performs better when interlaced coded (+ 1 dB).
Thus the two formats perform similarly (average PSNR : 0.17 dB more for progressive), except when the deinterlacing failed. In addition, the Kell filter, for progressive to interlaced conversion, acts as a post-filter to improve the picture quality of the interlaced decoder.

• **Progressive display** (progressive coding + display / interlaced coding + receiver deinterlacing) **:**

	Mobile		**Flower**		**Kiel**		**Renata**	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	31.30	27.51	31.41	26.59	30.36	26.10	31.12	27.18
PSNR (dB) U	34.26	33.28	34.10	33.68	40.47	39.21	35.55	34.24
PSNR (dB) V	32.29	31.44	32.30	30.83	39.15	37.85	37.47	36.32

Table 2 - PSNR (dB) for progressive signals

The only conclusion from the previous table is that the macroblock based deinterlacer does not perform very well. It means that very simple and low cost solutions can not be used, and that careful design should be done to reach an acceptable quality.

• **Interlaced / Progressive chain** (progressive coding + display / interlaced coding + display) **:**

	Mobile		**Flower**		**Kiel**		**Renata**	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	31.30	32.30	31.41	30.64	30.36	31.61	31.12	33.14
PSNR (dB) U	34.26	34.45	34.10	33.39	40.47	39.23	35.55	35.69
PSNR (dB) V	32.29	32.11	32.30	31.38	39.15	38.00	37.47	37.67

Table 3 - PSNR (dB) for progressive and interlaced broadcasting

From table 3 interlaced broadcasting seems better than progressive except for *Flower*. As a matter of fact, subjective evaluation show that, besides nearly 1 dB loss (for *Mobile*), the picture quality is higher with progressive encoding of interlaced sources because it removes the interlaced artifacts (flicker). In addition, the double resolution of the progressive original pictures explains the PSNR loss when progressive encoded, but the picture quality can be higher (fixed and detailed areas of *Kiel*), or lower (interlaced effects sometimes masks the coding artifacts of *Renata*) depending on the scene content.

From the three previous analysis, the following conclusions can be pointed out :

1)- An all progressive chain is generally preferred to an all interlaced one;

2)- In case of interlaced display, progressive transmission improves the picture quality of progressive sources compared to their interlaced versions, and the loss of resolution with interlaced sources (due to the interlacing filter) can supersede the reduction of blocking effects brought by the progressive encoding.

To explain these results, the following classification has to be done between sequences with similar vertical resolution and sequences with different vertical resolution, but also depending on the motion content. It leads to table 4.

1)- Without motion (*Mobile, Pendel, Pops, end of Renata*) : The pictures are frame coded in both formats, thus the spatial correlations and the motion performances are similar. The double number of pels of the progressive leads to a double bit-rate for I frames, but also for B frames since twice the number of vectors have to be transmitted (the bit-rate required for the macroblock header including motion vectors is 30% to 40% of the total bit-rate). For P frames the motion estimator performs better with progressive scanning (lower temporal distance), and the bit-rate required for the macroblock header represents less than 20%. However, it is not enough to prevent the 1 dB loss moving to progressive scanning in the case of interlaced source pictures, and this is increased up to 3 dB loss for progressive sources pictures because of the increased resolution;

2)- With motion (*Flower, Foot, Kiel, Kiel 2, beginning of Renata*) :The pictures are field coded. The number of motion vectors is the same in both case (2 fields vectors are transmitted per macroblock). It can thus be expected to have the same bit-rate for the B frames whatever the format is. In addition, once again progressive performs slightly better for the motion prediction, the bit-rate is thus expected to be lower than twice that of the interlaced P frames. Finally, the spatial correlation is probably better for progressive pictures, the bit-rate for I frames should not be too much higher than in the interlaced case. The result is 1 dB gain moving towards progressive scanning with interlaced source signals and 1 dB loss with progressive source signals (once again the additional 2 dB loss is due to the increased vertical resolution);

	Interlaced source		**Progressive source**	
	Static	Motion	Static	Motion
Prog/Int coding + Int display (Int/Int PSNR)	-3	-1	-1	+1
Prog/Int coding + display (Prog/Int PSNR)	-1	+1	-3	-1

Table 4 - PSNR gain (dB) moving towards progressive scanning

When interlaced display is performed for each format, 2 dB have to be subtracted to the performances of the interlaced original pictures, and 2 dB have to be added to those of the progressive sources (the first gain is due to an average value computed with less samples, and the second loss to a filtering effect).

2.3 Influence of the Bit-Rate

Is the comparison between progressive and interlaced scanning bit-rate dependent ? To answer this question, simulations on the sequence *Pops* have been performed at 2, 4 and 6 Mbit/s considering interlaced display. Table 5, clearly shows that if interlace is better at high bit-rates this is still true at low ones if not even more (from 0.6 dB at 6 Mbit/s, up to 1.7 dB at 2 Mbit/s).

The number of pels as well as the vertical and horizontal resolution are very critical at low bit-rates, and, even with interlacing, prefiltering is often required to smooth the picture content. If at high bit-rates the increased vertical resolution can be compensated, it is not true at low ones. Consequently, the performances of the progressive format decrease faster than those of the interlaced one at low bit-rates.

Bit-rates	**2 Mbit/s**		**4 Mbit/s**		**6 Mbit/s**	
Coding Format	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	32.17	33.87	36.35	36.99	37.98	38.58

Table 5 - PSNR (dB) at different bit-rates

2.4 Influence of the Picture Complexity

It has been shown that the conclusions differ depending on the picture content. Table 6 sum up the previous results by decreasing order of complexity value, referring to the original progressive sequences that have been interlaced. The PSNR can be considered related to the difficulty to encode a picture, thus it is selected as complexity measure (a high complexity gives a low value)

	Kiel 2 (28dB)		**Foot** (31dB)		**Kiel** (32dB)		**Renata** (33dB)		**Pops** (36dB)		**Pendel** (41dB)	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	29.17	27.81	32.23	30.84	32.11	31.61	33.49	33.14	36.35	36.99	41.25	41.87

Table 6 - PSNR (dB) for different picture complexity

From table 6, progressive performs clearly better for complex images and a little worse for pictures with a low complexity. The reason is that at low complexity the progressive format bring no additional information compared to interlace, and since twice the number of lines should be transmitted it results in slightly lowering the PSNR of the decoded pictures. However, since the gap is nearly equal to 0.5 dB, and since both progressive and interlaced PSNR are high, no noticeable difference between both formats can be seen.

2.5 Influence of the Deinterlacing

Moving towards progressive transmission will require conversions from progressive to interlaced and interlaced to progressive scanning to manage present studio environment. Thus the effects of the deinterlacing have to be studied to be sure that it handles field aliasing properly. Table 7 depicts the results of simulations performed on the Kiel 2 progressive source sequence by means of PSNR values (they refers to the original sequence that has been interlaced allowing for reliable comparisons). The original pictures are progressive encoded and interlaced displayed to give the PSNR value called *progressive* in table 6. Then the source is interlaced coded and displayed, and its PSNR computed in column *interlaced*. Finally, the previous interlaced sequence is *deinterlaced* to go back to progressive coding and final interlaced display.

Coding Format	Progressive	Interlaced	Deinterlaced
PSNR (dB) Y	29.17	27.81	28.36

Table 7 - PSNR (dB) between interlaced, deinterlaced and progressive signals

As expected, the deinterlaced sequence is better than the interlaced one, because the original progressive source performs already better than the interlaced version, and because the deinterlacing is artifacts free on that sequence.
However, these results are very dependent on the quality of the deinterlacer, thus conclusions may take into account possible low quality deinterlacing. Having in mind that future deinterlacing will become better and better.

3. Conclusion

In this paper, the coding efficiency of both progressive and interlaced scanning formats are compared by means of PSNR values and subjective picture quality analysis. The main goal was to evaluate the impact of using a progressive transmission format compared to the existing interlaced one. It leads to the conclusion that the absence of interlaced artifacts (mainly line flicker) allows the use of a greater compression factor in the case of progressive processing and display. At the same bit-rate an all progressive broadcasting chain, from the source capture to the final display, is thus preferable to an all interlaced one, except for an increased hardware complexity if twice the number of pels is scanned. Moreover, with interlaced display, the progressive transmission can be considered at least as good as the interlaced one and generally better if progressive sources are encoded. Unfortunately, the conclusions are not so clear when dealing with interlaced sources : the loss of resolution supersedes sometimes the reduction of blocking effects and the conversion from progressive to interlaced scanning after decoding can either improve (post-filtering of the coding artifacts) or decrease (loss of resolution) the picture quality depending on the source sequences available.
Consequently, it has been shown that progressive does not lead to a loss of performances, that on the contrary it brings a more stable picture quality, even if the MPEG-2 standard has been optimized for interlaced signals.
Thus, from a picture quality point of view, progressive scanning is a very attractive format for the transmission, and even more for the visualization of pictures. In addition, progressive can be used as an intermediate step towards progressive broadcasting of TV signals without loss of performances compared to the existing interlaced format. This is even more interesting when a smaller picture size is considered, to comply with the actual MP@ML profile (of course comparable picture quality is assumed).
Finally, if the MPEG-2 compression performances can not be significantly increased moving towards progressive scanning, compatibility with the multimedia applications (Computer, Broadcasting, Transmission, Virtuality, Film, ...) will be simplified and more efficient. This is perhaps the best way to go to.

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