UTILIZING HDTV DISPLAYS TO ITS FULL POTENTIAL AND ITS IMPACT ON VIDEO COMPRESSION

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ABSTRACT

For HDTV there should be a balance between spatial and temporal resolution. For obtaining this balance, while avoiding flicker and stroboscopic effects, the frame rate should be increased. A frame rate of 75 Hz is a good starting point. This is now possible, because the design rules for digital transmission are different from those of analogue transmission and there are options to remain compatible with the existing frame rate infrastructure.

Index Terms— HDTV, Displays, Motion analysis, Image de-blurring, Frequency

1. INTRODUCTION

For HDTV the resolution of the TV image is increased. However, in the present HDTV systems only the spatial resolution is increased, without simultaneously increasing the frame rate for improved temporal resolution. This can lead to disappointing results for TV applications, where movement is important. Until recently this problem was hidden by the limitations of LCD panels, in particular its slow response and "hold-effect" [1]. Recent developments, like increased maximum panel addressing frequencies and scanning (or blinking) backlight [2,7] enable the design of displays with good motion fidelity. The next step is to improve the motion fidelity of the signals that are supplied to the display. In present day TV sets, the frame rate is increased to 120 Hz, but the video content of the extra frames is more or less "guessed" from previous frames. Although in this way sometimes results are obtained that are satisfactory for standard definition (SD) television, High Definition (HD) TV is more demanding and is best served with a direct recording, broadcast and transmission of these extra frames. The present step from interlaced to progressive is an improvement already, however mostly for movements in the vertical direction. For improvement in the reproduction of the faster horizontal movements, more needs to be done.

This paper first of all treats the relations between motion blur and hold effect for three different TV systems. Next the hold effects in cameras and displays are treated, followed by the consequences for video coding and transmission and the conclusions.

2. MOTION BLUR AND HOLD EFFECT

When an object moves over the screen, the eye will tend to follow that object. Often a display is used that emits light during the entire frame period, like an LCD with a continuous backlight. Assuming that the panel uses a fast response LC material, the hold time of the display is approximately equal to the frame period time. In camera systems, the hold time is equal to the shutter time.

The cause of display motion blur is that, due to the hold time of the display, the displayed motion is not continuous but staircase like [1]. The eye however, can not make a staircase like motion, because the eye-ball makes a more continuous motion. This discrepancy causes motion blur in the eye, but can be solved in the display when the luminance output is pulsed like in a CRT display.

Any object can be described as a set of luminance waves. The shortest wave that can be found in an object is limited by the video transmission system; the higher the definition, the shorter the shortest wave length. When an object moves over the screen with a speed of one wavelength/hold time, the modulation depth of that wave is completely washed out. This washing out of details can occur in the human eye, as well as in the recording camera.

For a given hold time of the display, the higher the resolution of the TV system, the lower the speed at which the washing-out of the highest spatial frequency occurs.

For calculating the influence of the hold time on maximum speeds, the resolution capabilities of various TV systems has to be determined first.

For analogue TV systems the horizontal resolution of the system is given by the available video bandwidth for a TV channel and the time that is reserved for scanning one TV line. Typically the transmitted luminance bandwidth is 5 MHz and the active video line time is 54 micro seconds. Taking for analogue systems a tolerance based over-scan of 7% into account one finds a resolution of 250 luminance cycles per picture width (c/pw).

For digital TV systems, the definition of the maximum number of luminance cycles that can be displayed per picture width is calculated in a different way. For HD the number of pixels that is transmitted per line is 1280, for Full HD the number of pixels that is transmitted is 1920. One might argue that the maximum number of luminance cycles that can be displayed is half the number of pixels. However, that only holds when the maxima and minima of these waves just happen to coincide exactly with the pixel locations. When the maxima and minima of these cycles happen to coincide with locations just between the pixels, such a wave cannot be represented at all. Therefore it is generally accepted that the number of luminance cycles that can be represented reliably is around 0.35 times the number of pixels (Kell factor 0.7). This will be applied here. Thus we get the following table of resolutions for the analogue SD system, HD and FHD systems.

TV system	Max.resolution
SD (analogue)	250 c/pw
HD	450 c/pw
FHD	670 c/pw

Table 1: The resolution capability of three TV transmission systems, expressed in luminance cycles per picture width (c/pw).

Figure 1 gives the max speeds as a function of hold time for three TV systems, for the criterion of zero modulation depth for the highest spatial frequency during motion.

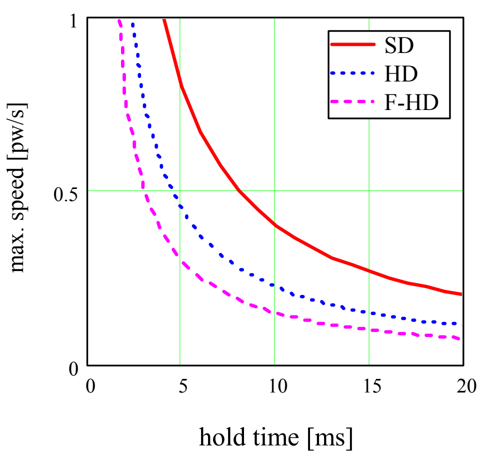

Fig. 1: The maximum speed at which the max resolution capability is just killed, for three TV transmission systems. The speed is expressed in picture-widths / second. (Note that this figure is independent of frame rate).

The effective hold time of the total TV system is a combination of the hold times of camera and display [3]. Therefore, one can conclude from figure 1 that the hold time of the display, but also for the camera, must be smaller than 8 ms for SD, 5 ms for HD and 3 ms for F-HD for speeds of ½ a picture width per second.

Speeds up to ½ a picture width per second do occur regularly [4] and at such a speed the human visual system is capable of resolving FHD resolution at a viewing distance of 4 times the picture height[5]

3. THE OCCURRENCE OF HOLD EFFECTS

3.1 Hold Effect in Cameras

First of all, the camera that is used to make the HDTV recordings should have a shutter time of less than 5 ms, preferably even 1 ms. Short shutter time camera's are often used for recording sport events. They even have to be used when recording images at a triple frame rate for the sake of supplying slow motion shots.

Shutter times can be chosen as small as one third of the frame time without running into "strobing" artefacts [6]. Once the frame rate is doubled, via motion compensated up-conversion or, better even, via recording at higher frame rate, the strobing effects are expected to disappear altogether.

3.2 Hold effect in LCD displays at 60 Hz

In a traditional (but fast LC response) LCD display the hold effect is equal to the frame period time. This leads, with a panel response time in this example of 7 ms, to the Modulation Transfer Function (MTF) for moving images shown in figure 3 by the continuous line. On the horizontal axis is the product of a spatial frequency and speed. With the spatial frequency expressed in cycles per picture width and the speed in picture widths per second, the horizontal axis has the dimension 1/sec or Hertz [Hz]. Note as an example that when FHD resolution of 670 c/pw has to be displayed at a speed of ½ pw/s, the MTF has to remain positive up to a frequency of 335 Hz. Here, in figure 3, the zero point of the MTF already occurs at a frequency of only 60 Hz.

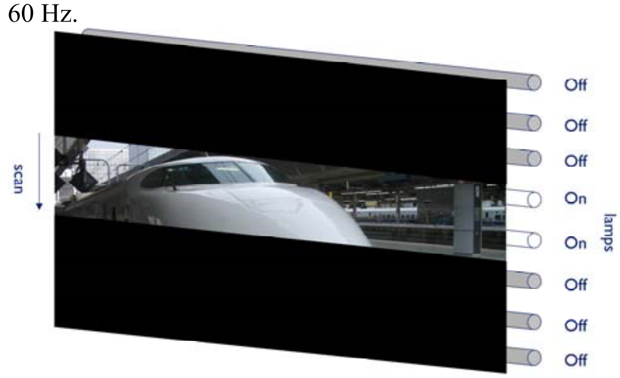

Fig. 2: The scanning mode operation of the backlight. By successive ignition of the lamps a light band scrolls over the screen, once for each frame.

But this can easily be improved by application of a so-called scanning backlight [2,7], which is sometimes called a blinking backlight. By illuminating each part of the screen only for a short while, as shown in figure 2, the hold time of the display can be reduced and motion fidelity improved. The amount of improvement is among others determined by the duty cycle of the lamps. This leads for a 35% duty cycles to an improvement as shown in figure 3 by the dotted line.

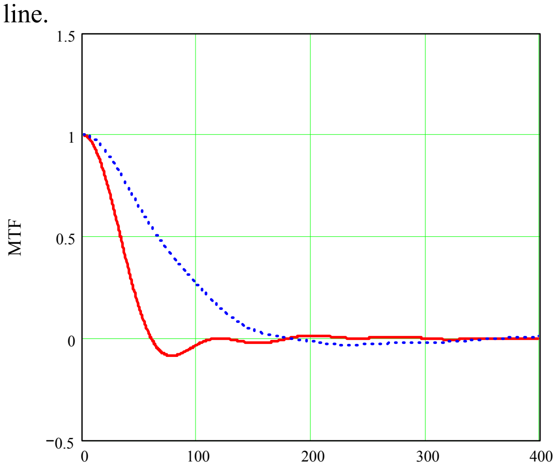

Fig. 3: MTF for moving objects of and LCD display, with panel response time of 7 ms, with (dotted line) and without (continuous line) a scanning backlight at 60 Hz frame rate. The horizontal axis is the product of a spatial frequency [c/pw] and speed [pw/s].

There is no limitation in what can be achieved with the scanning backlight. The example shown here is just what is now financially justified.

Difficulty here is that this causes flicker. This was not so obvious in CRT TV because of smaller sizes and smaller max luminance values. The most efficient way to reduce flicker is to increase the frame rate. Experience has shown that at a frame rate of 75 Hz flicker is sufficiently suppressed. However, LCD panel makers are now designing panels that can be used at frame rates up to 120 Hz, for the sake of easier frame-rate up-conversion from 60 Hz.

3.3. Hold effect in LCD Displays at 120 Hz

Also LCD panels that run at a higher frame rate of 120 Hz can be combined with a scanning backlight. Figure 4 shows, again for a panel with a rise/decay time of 7 ms, the moving object MTF for a 120 Hz display with a continuous backlight (continuous line) and a scanning backlight (dotted line). This combination of scanning backlight and 120 Hz frame rate leads to an MTF that remains positive up to 350 Hz. At this point, motion fidelity is improved without an adverse effect on flicker. But now the point is: how to get the proper video information to put into the display.

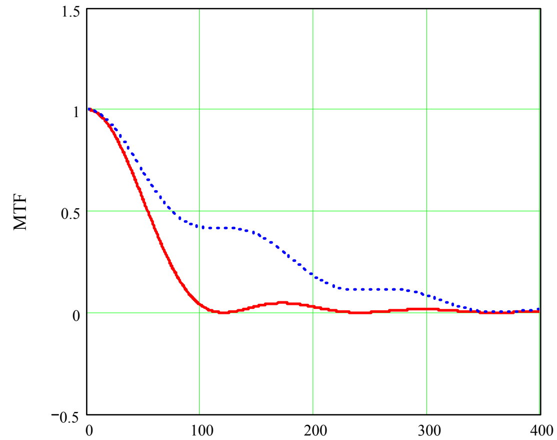

Fig. 4: MTF of and LCD display, with panel response time of 7 ms, for moving objects with (dotted line) and without (continuous line) scanning backlight at 120 Hz frame rate. The horizontal axis is the product of a spatial frequency [c/pw] and speed [pw/s].

4. CONSEQUENCES FOR VIDEO CODING & TRANSMISSON

At this point there are several ways to provide the extra video information. One is to apply frame up-rate conversion methods, but they all suffer from some problems. The only way to really get the motion fidelity right is to go to a higher frame rate in recording and coding & broadcasting. The minimum frame rate would then be 75 Hz.

Compatibility would be critical for the introduction of high frame rate TV (HFRTV) as well as the amount of additional bitrate needed for the increased frame rate.
One possibility is to provide a high frame rate enhancement layer, on top of the normal 50/60Hz rate video stream. This is something made possible by the new SVC video coding standard currently under development by JVT [8]. However in this case the frame rate of the enhancement layer has to be exactly a factor of 2 (or powers of 2) higher than the normal (base) video stream. Since the applied motion compensation (MC) in video coders is basically a 1st order approximation, the smaller the time difference between frames, the more accurate the MC becomes, and therefore the bitrate needed to compress frames at this higher frame rate becomes lower. Furthermore the additional bitrate can be kept low by the fact that all the enhancement layer frames can be of the B-frame type.
Table 2 is giving experimental results and is showing a decreased B costs/frame behavior. The average bit cost of the B frames is more than halved when the frame-rate is doubled from 30 to 60Hz. This B-frame behavior combined with keeping the anchor frames (I,P) always kept on the same frames for all frame-rates, meaning GOP parameters N

& M are adapted for each frame-rate, leads to the behavior of fig 5. for the total (base+enh.) bitrate.

frame-rate	N	M	#P/gop	#B/gop	B costs/fr
15	8	1	7	0	0
30	16	2	7	8	0.296
60	32	4	7	24	0.135

Table 2: Experimental results based on H264 ref SW based on the ParkRun sequence showing B costs/frame.

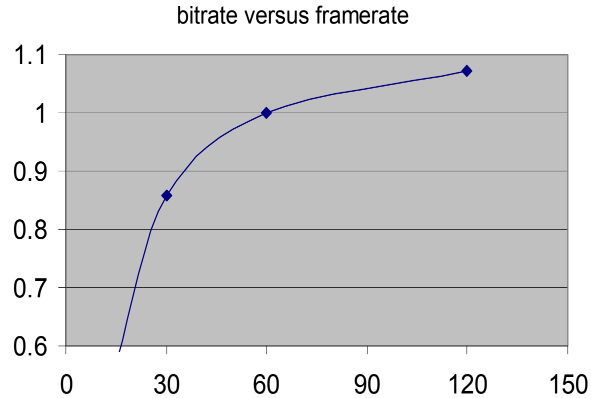

Fig. 5: The type of general behavior of total bitrate (normalized at 60Hz) as a function of frame-rate [Hz].

These results differ from earlier investigations [9], where the previous frame was used as a reference frame (IP coding). The results in this paper however, are based on achieving the additional frame rate for HFRTV by the use of additional bi-directional predicted frames.
Also for achieving low additional bitrate the use of the so-called hierarchical B-frames prove to be beneficial.

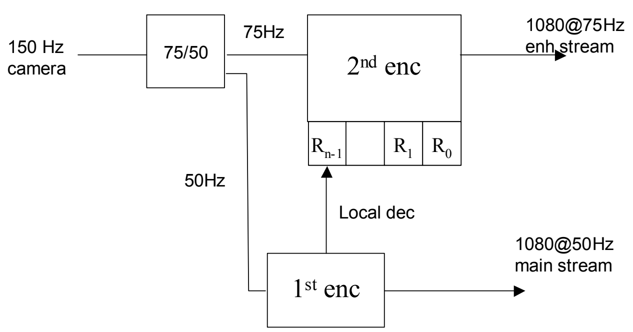

Fig. 6: Scheme for efficient video coding of arbitrary ratio of frame rate between base & enhancement layer. (R_i are reference frame memory locations).

Another possibility is to modify an existing video standard such as H264/AVC, such that local decoded frames from an normal (standard frame rate) stream created by the 1st encoder can be used as a predictor for the second encoder.

Such an arrangement, as shown in figure 6, would allow for any frame rate ratio to create efficiently a high frame-rate enhancement layer, not just for a factor of 2 between the base and enhancement video.
This type of solution allows more freedom in the choice of the enhancement frame-rate, so this frame rate doesn't have to be higher than really needed based on the considerations of chapters 2 &3, and therefore limiting the additional bit-rate for the enhancement layer to the very minimum (a good example would 75/90Hz enh. on top of the 50/60Hz standard rate).

5. CONCLUSION

A higher frame rate at recording and transmission is the best way to achieve a motion fidelity that is in line with the HDTV spatial resolution requirements. Video coding solutions do exist to both provide for compatibility with normal frame-rate video and at the same time to keep the additional bit-rate to a very acceptable low level of in the order of 10%.

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