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Abstract

With the recent rapid growth in the number of television formats systems and data compression, it has become rather difficult to establish exactly how they relate to each other. There are frequent arguments over whether one system is better than another, usually supported by reference to image dimension and chroma sub-sampling algorithms, but none of the number sets adequately describes the viewers’ experience of resolution.

This paper proposes a new unit, intended to express the relationships between sampling structures and image formats in a human way, and I have christened it the “Rel” (unit of relative resolution).

Additional key words: resolution, sub-sampling

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The "Rel": a perception-based measure of resolution

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1 Introduction

An aspect of television that frequently causes heated debate is the resolution limits of the various formats, how to express them and how they relate to each other, and how HDTV relates to SDTV. Calculations based on the published properties of the formats can be misleading and used to grind axes, therefore I have calculated the relationships from scratch.

Clearly, some new measure is needed that relates formats to each other in a meaningful way, but first I need to illustrate the problem.

2 Resolution of Cameras

There are four basic resolutions of cameras in use today, tabulated below. There are new variants of these, but they need not worry us for the time being. The numbers most often quoted are for "total pixels per frame", since that gives the biggest number that can be claimed, but perhaps the square-root of that number more closely resembles the impression to the viewer.

	Pixels	Lines	Total	√Total
SDTV (60)	720	487	350,640	592
SDTV (50)	720	576	414,720	644
HDTV (720)	1280	720	921,600	960
HDTV (1080)	1920	1080	2,073,600	1440

Unfortunately this does not seem particularly helpful as it does not supply easily digested data, the numbers are too big to comprehend easily. Also, it takes no account of interlace.

When a signal is interlaced, the vertical resolution is reduced by approximately $1/\sqrt{2}$ since only half the lines are presented to the viewer at any instant, but persistence of vision provides some of the image fusion needed to retrieve the "lost" resolution. Various measurements and calculations have been done to establish the true value for this parameter, values between 0.53 and 0.85 have been quoted but there is no definitive answer so I choose to use $1/\sqrt{2}$ for simplicity. Even so, the bare numbers are not very helpful, what is needed is a relationship that more closely models the performance of the eye, probably a logarithmic element, since many parts of human perception seems to behave logarithmically.

Therefore, I have introduced a logarithmic element by arbitrarily expressing each format relative to the dimensions of 50Hz SDTV, and this seems to quantify more closely the true impression of the relative resolutions of the formats. I have also arbitrarily decided that a factor of 10 in total pixel numbers can be a benchmark and called it a "Rel" (relative resolution) and have thus derived the formula for the "deciRel", or dR, as 10*LOG(pixels/pixels50I). Thus the perceived resolution of any format, relative to SDTV at 50Hz interlaced, is 10*LOG[(width*height)/(720*576/√2)]. If the target format is also interlaced, then the $1/\sqrt{2}$ factor must apply to it as well. I make no claim as to the visibility levels of the Rel or deciRel (dR), only that this relative scale is more likely to seem relevant to the viewer than any linear measure might.

This more complete table below shows the calculations. Note that the reference resolution (0dR) is for interlaced SDTV at 50Hz, since that is what is commonly viewed in Europe.

	Pixels	Lines	Total	dR (Interlace)	dR (Progressive)
SDTV (60Hz)	720	487	350,640	-0.73	0.78
SDTV (50Hz)	720	576	414,720	0	1.51
HDTV (720)	1280	720	921,600	N/A	4.97
HDTV (1080)	1920	1080	2,073,600	6.99	8.49

SDTV exists in Progressive forms only for scanned films, and for pictures shot with genuinely pro-scan cameras such as the Panasonic SDX900, or when down-converted from HDTV. The vertical resolution of an interlaced frame cannot reach the total number of lines because that would cause "interlace twitter" where the eye cannot distinguish between high vertical frequencies and low temporal frequencies. Also, 720-line HDTV does not exist in interlaced form at all. The two columns on the right seem to quantify the subjective viewing experience of resolution for the formats. Clearly, moving from interlaced to progressive gives an improvement that accords reasonably with observations, and 720P neatly slots in as being similar to but not as good as 1080I, again closely matching observation.

For the dR calculations I have used an equation based on the "power" dB relationship because we are dealing with areas rather than linear dimensions, so the equation is 10*LOG(pixels/pixels50I) rather than 20 times. The factor of 10 allows for the deciRel, but this does not imply that one dR is a visible increment, although it seems to approximately so.

3 Resolution of Recording Formats

Many calculations have been made and quoted, based on the known "4:2:2" sampling structure of SDTV production; values such as "3:1:1", "22:11:11" have been quoted, but they are related to the electrical properties of the systems and not to what the viewer sees. The first number in the triplet describes the number of luma samples in a group, the second and third describe the number of chroma samples (each of Pb and Pr) in the same group. Note that this format deals only with horizontal sampling unless the third value is zero, in which case the chroma samples exist only on alternate lines of the field (interlaced) or frame (progressive). Initial calculations are made using the known sampling and sub-sampling schemes used in the various HDTV formats.

HDTV capture formats generally filter and/or sub-sample the data prior to tape compression. The following table lists the known schemes.

	Pixels	Filter	Sub-sample	Pixel numbers	Ratio relative to SDTV
SDTV	720	1:1	4:2:2	720:360:360	4 : 2 : 2
HD (Pan 27F Varicam)	1280	4:3	4:2:2	960:480:480	5.3 : 2.7 : 2.7
HD (Pan 20A 60Hz)	1920	3:2	4:2:2	1280:640:640	7.1 : 3.6 : 3.6
HD (Pan 20A 50Hz)	1920	4:3	4:2:2	1440:720:720	8 : 4 : 4
HD (Sony HDCAM)	1920	4:3	3:1:1	1440:480:480	8 : 2.7 : 2.7

Again, the numbers in the right-hand column take no account of the number of lines and so do not describe what the viewer actually sees. For that, we have to multiply by the number of lines and take account of interlace with the 1/√2 factor again where relevant. Again, I use the dR formula to express the result logarithmically. The reference for the final columns is the frame size of SDTV at 50Hz, but interlaced.

						Interlace	Proscan
	H	V	Filter	Sub-sample	Total	dR	dR
SDTV 60Hz DV	720	487	1:1	4 1 1	350,640 87,660 87,660	-0.7 -6.8 -6.8	0.8 -5.2 -5.2
SDTV 60Hz	720	487	1:1	4 2 2	350,640 175,320 175,320	-0.7 -3.7 -3.7	0. 8 -2.2 -2.2
SDTV 50Hz DV	720	576	1:1	4 2 0	414,720 103,680 103,680	0.0 -6.0 -6.0	1.5 -4.5 -4.5
SDTV 50Hz	720	576	1:1	4 2 2	414,720 207,360 207,360	0.0 -3.0 -3.0	1.5 -1.5 -1.5
HDV 720	1280	720	1:1	4 2 0	921,600 230,400 230,400	N/A	5.0 -1.0 -1.0
HDTV Panasonic 27F	1280	720	4:3	4 2 2	691,200 354,600 354,600	N/A	5 0.7 0.7
HDTV 720 Panasonic "D5"	1280	720	1:1	4 2 2	921,600 460,800 460,800	N/A	5.0 2.0 2.0
HDV 1080	1440	1080	1:1	4 2 0	1,555,200 388,800 388,800	5.7 -0.3 -0.3	7.3 1.2 1.2
HDTV Panasonic 20A 60Hz	1920	1080	3:2	4 2 2	1,382,400 619,200 619,200	7.0 2.2 2.2	N/A
HDTV Panasonic 20A 50Hz	1920	1080	4:3	4 2 2	1,555,200 777,600 777,600	7.0 2.7 2.7	N/A
HDTV Sony HDCAM	1920	1080	4:3	3 1 1	1,555,200 518,400 518,400	7.0 1.0 1.0	8.5 2.5 2.5
HDTV Sony HDCAM-SR, Panasonic "D5"	1920	1080	1:1	4 2 2	2,073,600 1,036,800 1,036,800	7.0 4.0 4.0	8.5 5.5 5.5
HDTV Sony HDCAM-SR	1920	1080	1:1	4 4 4	2,073,600 2,073,600 2,073,600	7.0 7.0 7.0	8.5 8.5 8.5

4 Resolution : using the deciRel

Being a logarithmic calculation, the dR values can be added to see the effects of varying several parameters. For example, the effect of interlace is, I have assumed, a factor of 1/√2 on the line numbers, thus its effect is 10*LOG(1/√2)≈-1.5dR, and this can be applied to any image format or resolution to find the effect. Similarly, the 50% horizontal sub-sampling of chroma signals in 4:2:2 system results in a value of 10*LOG(1/2)≈-3dR, as does the vertical sub-sampling in 4:2:0. All these values can be added to find the overall effect. Similarly, the effect of changing pixel count or line number can be separated, from 720 pixels to 1280 is 10*LOG(1280/720)≈2.5dR and from 576 lines to 720 lines is 10*LOG(720/576)≈1.0dR. Thus the resolution change from interlaced 576-line SDTV to progressive 720-line HDTV is 1.5+2.5+1.0≈5.0dR, value found in the entry for the D5 720P format, with 3dR subtracted for the 4:2:2 chroma sub-sampling.

Intuitively, it seems that the limit of visibility is around 0.5dR, so perhaps the factor of 10 in the dR calculation should be 20. But until more work is done (if any), I propose to leave things as they are since the measure seems to render an accurate impression of the relationships between the standards.

The reader should bear in mind, however, that these calculations are all done on the limiting resolutions of the formats, and not on the image information content nor on any filtering done on that content. It is well known that some camcorders appear to produce sharper pictures than others that have, apparently, greater limiting resolution. This is caused by detail-enhancement tricks designed specifically to have this effect and by the use of filters with sharp cut-off characteristics that induce ringing which masquerades as extra sharpness.

Also, since the calculations are only on the format dimensions and not on the viewed results of using those formats, they assume that an appropriate display is viewed from an appropriate distance for each format. For all of the calculations to be meaningful, each format should be viewed on a display of suitable size, positioned such that one display pixel subtends a viewing angle of about one minute of arc (1/60°) at the eye. The following table lists the display sizes and viewing distances that make sense for the formats covered.

	Aspect ratio	H	V	Distance for 25/28” display	Size for 3 metre distance
SDTV 60	4:3	720	487	2.4~2.7m	30.9~27.9”
SDTV 50	4:3	720	576	2.4~2.3m	30.9~33.9”
SDTV 50	16:9	720	576	3.0~2.1m	28.4~40.4”
HD 720	16:9	1280	720	1.7m	50.5”
HD 1080	16:9	1920	1080	1.1m	75.7”

The fifth column shows the required viewing distance for a typical UK display (25” diagonal for 4:3 (20”x15”); 28” diagonal for 16:9 (24.4”x13.7”), the two values are for the horizontal and vertical pixel to subtend one minute of arc to the viewer. For the HDTV formats, the pixels are square, so the two distances are the same. The sixth column shows the required display size (again, diagonal) for a 3 metre viewing distance (again, a typical UK viewing distance), again for horizontal or vertical pixels to subtend one minute of arc. I apologise for mixing Imperial and SI units, but I suspect that they are more meaningful this way to the majority of readers.

5 Conclusion

The deciRel appears to give a reasonably good relative placement of various format resolutions, using only a single calculated value, which can be manipulated in the same way that the decibel can for acoustic and electrical signals. The exact scaling may not be important, since I have invented it purely for ranking purposes, but perhaps subjective testing could be used to produce a more accurately scaled version that correctly assigned values to resolution. Also, the present formula treats luma and chroma signals identically, perhaps the chroma channels should be differently scaled to allow for the known lower resolution of human vision to chroma relative to luma.

Even if further investigative work is not done, the present formula offers a useful way to establish the relationships between formats.

If nothing else, this document should at least provoke some thought and discussion of the problem.