The Colorimetric Characteristics of Digital Cameras

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Imaging Science Topic 1 : The colorimetric Characteristics of Digital Cameras

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1. Basic Response Characteristics

A colour imaging device has three essential components.

1. The optical system designed to register an image on the sensing system
2. A sensing system capable of responding dynamically to a suitable range if incident light intensities.
3. An N-channel light-energy differentiating system that is capable of yielding reproducible colour co-ordinates.

In general, these three systems allow an image to be recorded that is an acceptable reproduction of the imaged scene.

In the totality of possible scenes that may be imaged, there is a range of both colours and light intensities, that can not be accommodated within a linear response range on any currently available sensor system. This is true of photographic film, and even more so for currently available digital sensors.

As a direct consequence of the limited dynamic response range available, imaging system design must be a compromise.

1.1 The response to light intensity

In general photographic film has a Log-Linear 's-shaped' response curve :-

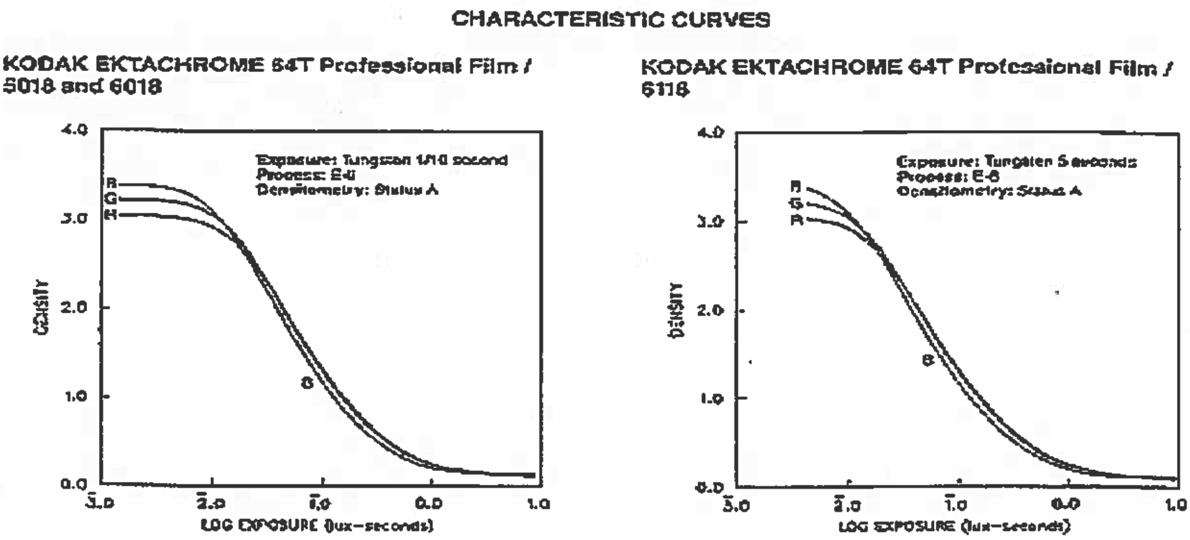

Fig.1- Characteristic Curves for Kodak 64T Professional Slide Film.

Note that for film, Density after exposure is the inverse analogue of the linear photon-energy response of a typical CCD imaging array. Note also that the above film has about a 7 f-stop useable highlight-to-shadow dynamic range. In practice this means that fairly high-contrast scenes, with both highlights and shadow, can be accommodated in a reasonable image.

The close correspondence between the three colour channels is also important, as it delivers a balanced neutral response across the full dynamic range of response.

While the response curves of CCD imaging arrays are fundamentally different, the end result is often similar. As 'full well' capacity, i.e. receptor saturation is reached it demonstrates a similar asymptotic approach to the theoretical maximum output.

The tailing off to zero response is similarly non-linear, because of the incidence of thermally generated electrons.

1.2 Colour-channel Response

Adequate Blue-channel response is reasonably easy to obtain with film, and much less easy with CCD sensing. In general the colour channels must be given 'broad-band' response characteristics. This is important, in order to generate sufficient signal-to-noise ratios in each channel, particularly when representing shadow detail.

In Fig 2. Below, some response curves are plotted for the DCS 520 digital camera.

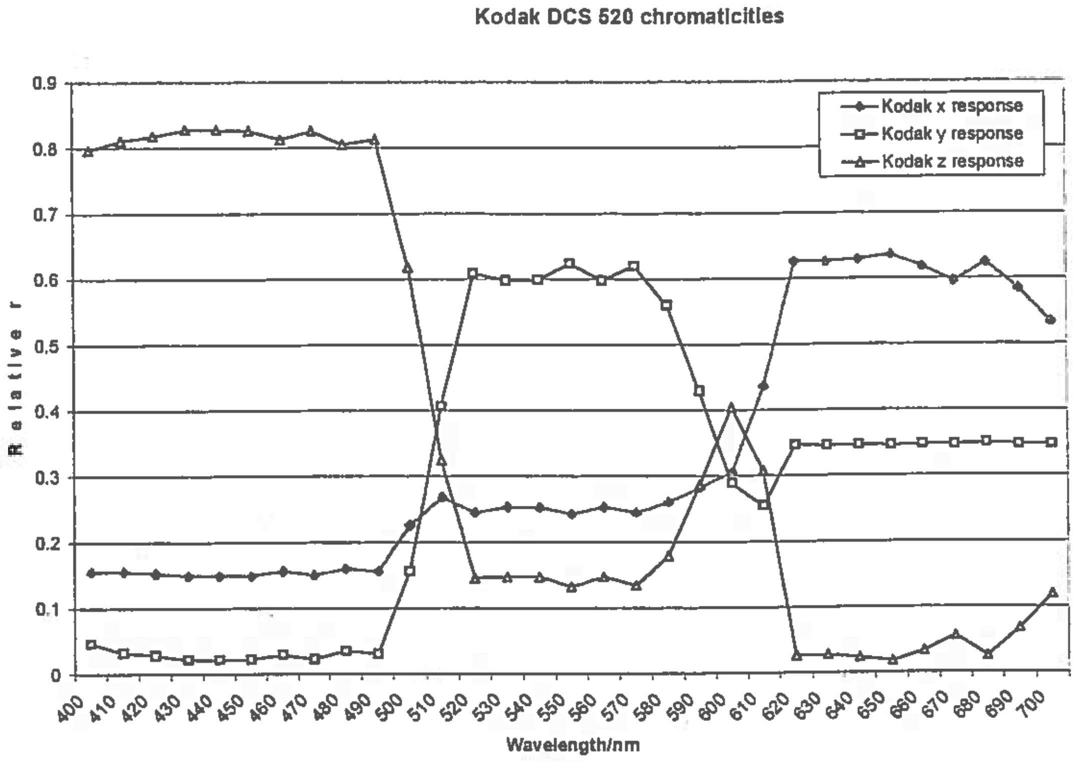

Fig 2. The relative channel response of the DCS 520, expressed as spectral chromaticities.

Note that the blue channel response has been artificially enhanced with a secondary sensitivity in the yellow region.

This has the effect of lightening and desaturating the response to high Chroma blue stimuli It also means that pure bright yellows will be desaturated to near white. This is not nearly as bad as it sounds. Even a marginal increase in bandwidth of the stimulus will restore the 'yellowness' of the overall camera response (represented as a predominant R + G response).

Desaturated blues and yellows are a relatively small compromise to pay in comparison with obtaining an overall reduction in 'colour-noise', and a generally well balanced colour reproduction.

Fig 3. below shows the co-ordinates of Fig 2 plotted in the CIE chromaticity diagram

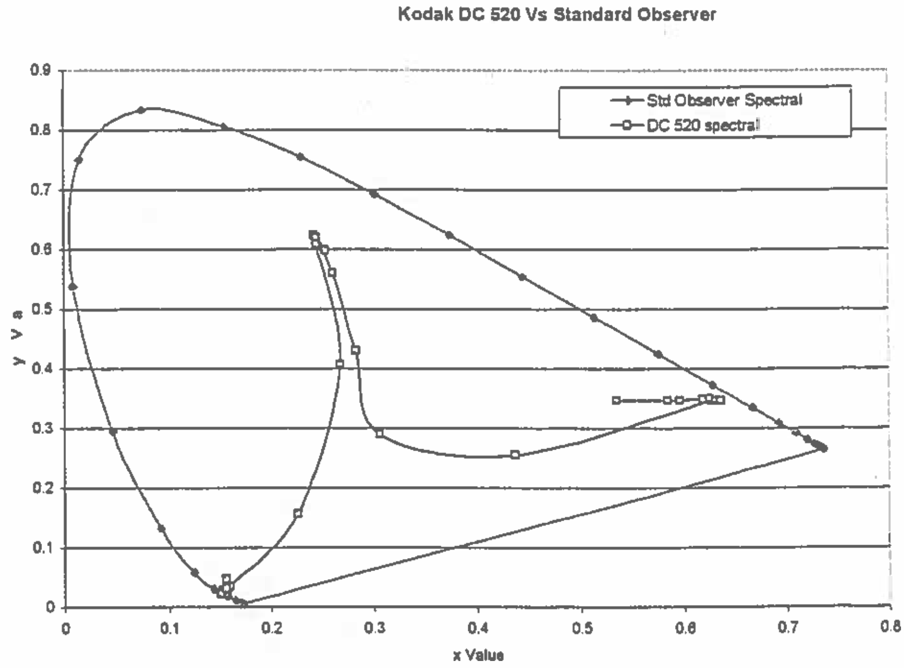

Fig 3. Camera response to Spectral Stimuli.

The camera produces images of any given scene, that are a reasonable compromise reproduction. It alters the precise CIE specifications of the objects imaged substantially in a process termed " Instrumental Metamerism", reflecting the compromises in its colorimetric design.

Imaging a grey-scale with this camera reveals that there are also, potentially more obvious, compromises in the contrast range highlight-to-shadow, that it can capture. The linear central portion of its contrast range was at most 5 - 6 f-stops or a ratio of less than 50:1 in light intensity. Users of such a camera would have to be very careful of correct exposure, and would probably have to sacrifice either shadow or highlight detail to obtain an acceptable image.

1.3 The use of non-linear response to compress the gamut of correctly reproduced colours

A valuable compromise of response range is available by introducing a 'gamma curve' characteristic in the output of the camera. The effect is to smoothly compress a much larger dynamic range onto the limited (usually 8-bit) channel resolution. The shape of the curve also gives maximum differentiation, and emphasis of mid-range colour and lightness differences.

In terms of CIE XYZ colour identity space, differences relating to highlight and shadow detail are compressed into relatively small volumes of device space. Equally, the scaling of chroma is quite strongly compressed, emphasising the differences nearer the neutral point and compressing those toward the spectrum locus.

The designer of a digital camera has not got a free hand in choice of response gamma however. It must in general be reasonably closely matched to that of the reproduction device chosen for hard or soft-copy output of the images.

1.4 Negative Lobe gamut compression

It is common practice, particularly in video camera design to insert a 3X3 matrix cross-dependency between raw-receptor RGB values and output R'G'B' values. The matrix re-defines the primaries as containing negative quantities of the alternative components. In effect this pushes the 'virtual camera primaries' further out in the chromaticity diagram. In consequence, many more colours fall inside the triangle of reproducible colours.

There is of course a downside to this. Colour difference resolution is significantly reduced by the adoption of negative lobe compression. It is well known however, that the overall colour reproduction is significantly improved by this method.

The CIE colour co-ordinate system uses negative lobe compression, to bring all real colours into the gamut of 'all positive' XYZ combinations. As CIE co-ordinates are *real numbers of arbitrary precision*, compressing the scale on which they are measured in of no consequence.

Summary

1. The overall response characteristics of both digital and film cameras can be analysed in terms of the CIE co-ordinate colour identity of device output variables.

2. If this is done, the compromises used to achieve good general picture reproduction can be identified and analysed.

3. Compromise is necessary due to the limitations of sensor technology. Compression may also be used as a specific strategy. to improve the general appearance of (particularly hard-copy) output. Printed images have inherently reduced contrast range compared to that in the scene imaged.

4. Even large compromises of object chroma, as shown in the DC 520 results, do not cause serious distortion of visual colour rendering in the final image.

5. Users are much more likely to object to even relatively small inaccuracies of colour balance. This has often lead to the inclusion of automatic colour balance features in cameras. These correct for illuminant colour temperature, keeping the system in balance at the neutral point.

6. The 's-shaped' response curve of typical sensors is highlighted. It serves to sacrifice detail in highlights and shadows, whilst maintaining a good response to mid-range detail.

7. The effect of a 'gamma-curve' characteristic is stressed as a strategy that compresses a much larger dynamic range of possible output responses non-linearly, onto an 8-bit linear output scale.

8. Negative lobe matrixing is demonstrated, as a method of defining 'virtual response primaries'. Negative lobe matrixing is in effect present in the human visual response. The use of a careful combination of raw channel response, and negative lobe matrixing can give the camera a very close approximation to the human visual response. (See also Instrument Metamerism).

9. 'Negative lobe Compensation' is commonly used in broadcast video cameras. It has been demonstrated that its effect is to improve overall colour reproduction.