Hybrid Production Environment

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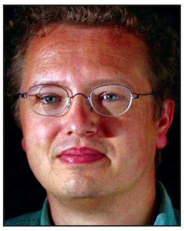
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Today's workflows require the use of various acquisition and data sources. In order to keep the acquired data formats compatible with traditional film acquisition, some major problems need to be addressed. First, when acquisition is done via digital camera and traditional film camera, the final cut between shots often shows dramatic differences in color, depth of field, and quality. Studies will be presented about digital camera shots (HD material), acquired with a functional model of a digital film style camera. Second, in post-production most facilities have to work with scanned material that comes from various sources (telecines, scanners). This often results in differences in colors and dynamic range. Technologies that can be used to compensate between different source materials will be discussed. Finally, colors are the most crucial element in a hybrid production chain. Preserving colors from acquisition, scanning, recording, and projection is one of the most sophisticated tasks during production. Color management will be considered as a throughput solution.

Motion picture images may appear to offer an objective representation of a photographed scene but they remain an optical illusion—one based on very discrete sampling of available visual information. In most cases, the goal of the moving images is to create an impression of an actual experience. A large palette of visual cues is available to the creative team involved in the capture and processing of the images. These can be photographic representations of real scenes as well as artificially created elements. Individual aspects of the images can today be modified at will. In the end, however, it is the audience that will have to decide whether the illusion has worked or not. A truly objective evaluation of the achieved quality is not possible because measurable image parameters will always have to be considered within the context of the impression that the images are trying to invoke.

The creation of motion pictures has of course been shaped to a large extent by the technology of film. The existence of the term "film-look" shows that there is a certain consensus among audiences, of how the illusion of motion pictures should be presented. It is clear that this technology has some very basic limitations, which in turn lead to quite obvious artifacts. A typical example is the "strobing" that can be observed in vertical line when a film camera is panned too quickly. On the other hand, one of the great advantages of the medium is its long history. A great experience base has developed that allows filmmakers to work very effectively within the given limitations. In fact, some of the artifacts are so well-known that they have become visual elements in their own right.

With the introduction of digital technology to the process of motion picture creation, new challenges have arisen. In today's hybrid production environment, new creative tools must integrate visually with existing technologies. At the capture end, digital cameras must give the creative users enough control to create images using the same visual language to which they are accustomed. In many cases, it will make sense to use both film and digital capture side-by-side, utilizing the specific advantages of each medium respectively. In this case, it is especially important for the images to match.

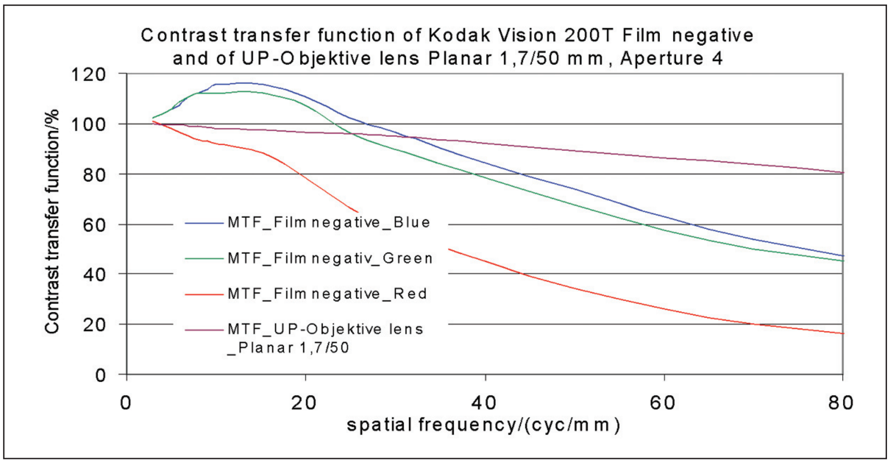

Figure 1. Resolution of film negative material and film camera lens.

In the post-production of the images, the hybrid approach requires just as much care. In an environment where a large percentage, if not all of the captured material is digitized, almost every visual aspect of the images can be modified. This in turn makes it increasingly difficult to define where in the process the actual "look" is created. To further complicate the issue, the evaluation of the visual impression depends very much on the chosen display medium. This may change several times within a hybrid production: from the first rushes of developed film projected in a viewing room, to computer monitors in digital post-production, and back again to projected film that has been recorded with a film recorder. If care is not taken, the visual impression can be vastly different with each display medium, which may result in the wrong creative decisions and an inferior final release.

Tests have shown that measurable image parameters alone are insufficient in describing the impression that a moving image will create. This paper will present a more in-depth analysis of these visual parameters and attempt to show how they have been employed within the context of the cinematographic illusion. Moreover, it will show how these parameters need to be selected or controlled to allow the creation of the intended visual impression as well as its preservation through the various stages of post-production and distribution.

Visual Parameters

Resolution

The resolution of an imaging system can easily be determined using quantifiable test charts that contain structures at various spatial frequencies (Fig. 1). The response of the system can be analyzed in relation to the orientation of the structures as well as to their location in the image field or their spectral content. The response of the system over spatial frequency can also provide a characterization of the system.

Next to these quantifiable parameters, the occurrence of artifacts—visual information that does not belong to the intended content—can limit the resolution. These can include interference patterns caused by the interaction of a recurring pattern in the scene with a structure in the capture medium.

Even such detailed parameters are not sufficient to completely describe the impression of an image. The central problem lies in the substantial difference between a photographic system and the visual system, eye/brain. The photographic system transforms three-dimensional space into a planar image; specifically, it transforms each point in space into an area of varying size in the image plane. The exact nature of the transformation depends on the geometrical situation (focus) as well as on the quality of the imaging system. An ideal system will transform the points of exactly one plane in space into points on the image plane. In a real system, points are transformed into areas that approach a relative minimum when the system is in focus. The closer the ideal of a point-to-point transformation is achieved, the better the resolution.

In contrast, human vision is much more flexible. The eye is not set to a fixed focus, but instead is constantly varying the focal plane in search of stimuli that contain information. When an object of interest has been identified, the brain activates a whole set of mechanisms to gather more information. This includes focusing of the eyes on the object plane, but may also involve mental comparisons with known objects, evaluation of size and distance based on visual cues, use of further senses, etc.

If a viewer is presented an image on a screen, his eyes will at first register a known visual stimulus. However, due to the fact that he is only viewing a two-dimensional, spatially limited image, many additional stimuli that exist in the real world will be missing. The viewer has to be satisfied with a planar image of space, exhibiting a fixed distribution of resolution based primarily on how the focus was set in image capture, but also on the quality of the imaging system. His impression of the image will now depend on how his desire for visual information is satisfied. An example: the overall resolution of a portrait may be artificially reduced (diffused) to provide a flattering effect. The viewer will still accept the image as pleasing if enough visual clues are available (e.g., to judge the mood of the talent). If on the other hand, a portrait were shot with a high level of resolution but a very limited depth of field, this might result in a significant facial element such as an eye being out of focus. To judge the mood of the talent, the viewer would seek to obtain more information, causing his eye to automatically attempt to refocus. Because this cannot lead to the desired effect in a two-dimensional image, the viewer is irritated by the image.

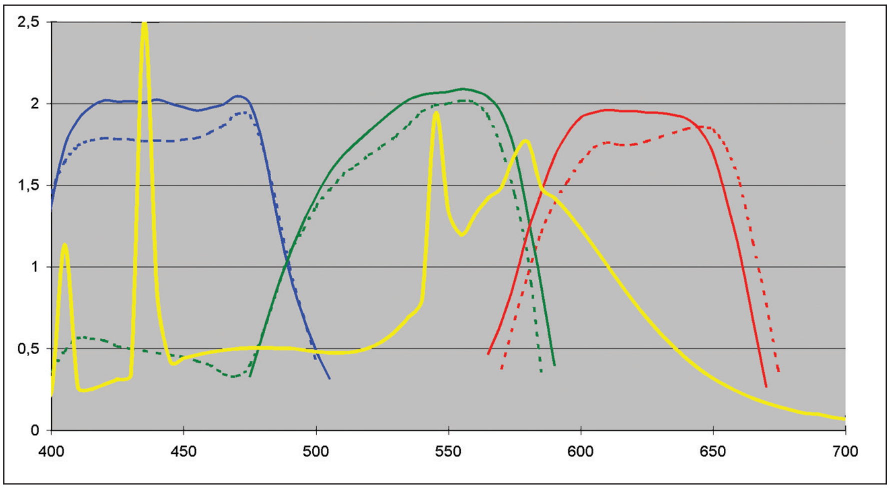

Figure 2. Four-layer film technology for the Negative REALA 500 D (continuous line) in comparison to a conventional negative film 250 D (dotted line) of Fuji and a fluorescent lamp spectrum (yellow line).

The distribution of resolution in an image is an important creative aspect because it allows the cinematographer to direct the attention of the viewer. The maximum resolution applied is completely relative, and thus it is difficult for a viewer to specify a direct relation between resolution and image impression.

Color Representation

Color representation is commonly evaluated by the comparison of colored test objects. Standardized test panels that cover a given color space in certain increments are available for this purpose. Aside from this, there are various subjective methods available for testing color reproduction. Any number of test objects can be utilized for these tests, with the analysis relying on a comparison of the viewed scene (or the memory of the scene) and the image. The representation of specific image elements may have a higher priority than other elements.

A good example is the representation of skin tones. The viewer tends to judge how “natural” the skin-tones are reproduced (e.g., a comparison with personal experience is automatically carried out) (Fig. 2).

The existence of artifacts can also influence the evaluation of color representation, especially if they do not pass mental plausibility checks, for example colors do not match contours, or colors are visible in areas that are colorless by experience.

More than any other image parameter, however, color is a matter of taste. This is essentially because of the incredible adaptability of human color vision. The human eye/brain system has developed in such a fashion to be able to differentiate color stimuli in a large range of lighting situations. The constant comparison with personal experience allows a standardization based on objects of an identified color.

Cinematographers often take advantage of this attribute by using colored filters for the camera or for the lighting. The audience accepts false or irritating color stimuli as a part of the total image impression.

Dynamic Range (Exposure Latitude)

Dynamic range is commonly measured as a ratio of

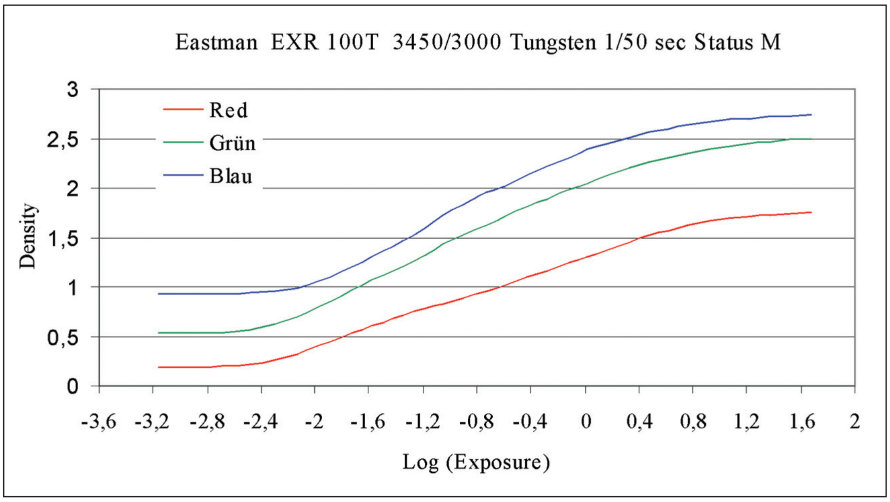

Figure 3. The dynamic range of motion picture film, measured by Arri-lab.

useful signal to the noise level in the image. A visual evaluation is also possible using scenes containing a large range of illumination levels, usually exceeding the expected dynamic range of the imaging system (Fig. 3). The evaluation involves several criteria including:

- Differentiation of small differences in illumination level range of linear transformation performance at the limits of the system.

Additionally, subjective criteria must be considered:

- Reproduction of immediately adjoining areas with greatly differing intensity.
- Reproduction of finely structured but generally monochromatic areas (e.g., skin, textiles, stone artifacts such as blooming, stripes, reduced resolution).

As with resolution, human vision is very flexible with regards to variations in brightness. A photographic imaging system could theoretically be designed to offer a similar flexibility but this in itself would create a problem: if a viewer were presented an image containing an obviously over-exposed area, his visual system would automatically attempt to gain more information by adjusting the pupils. However, because the image itself is over-exposed it lacks additional information, which irritates the viewer. If the imaging system were to modulate the exposure level over time in the same way that the human visual system does, this would only create a greater irritation because the modulation would not be linked to the viewer's own desire for additional information.

It remains a creative task to select a specific distribution of brightness in the image in such a fashion that the viewer will not feel the need to seek further visual information from the image.

Motion Representation

The illusion of continuous motion created by the display of incrementally changing images is subject to very strict limitations. If certain requirements are not fulfilled, the illusion breaks down and the viewer will perceive elements of the individual images. The parameters that govern the quality of the motion illusion are to some extent quantifiable through audience testing. These parameters include:

- Rate of image refreshment
- Rate of display
- Phase ratio between image display and darkness
- Image capture time (motion blur)
- Rate of spatial displacement of image elements in relation to the image size

Tests have shown that human motion resolution is not particularly well developed, as can be shown by the relatively low frame rates that are required to create the illusion of motion. This leads to many possibilities of varying the parameters of motion representation to create a desired effect while upholding the illusion of motion for the audience.

In addition, the motion represented in the image content can take on many different forms. Object motion, for example, is perceived differently depending on its spatial relation to the image boundaries. Camera motion can be added to complement the object motion. A dynamic variation of the focal length of the lens (zoom) also provides additional motion elements. The creative combination of these elements can be used to support the illusion of motion and can even compensate certain deficits in the motion representation. An example is a fast pan across vertical image elements. If the spatial displacement of the elements from one image to the next is too large, the viewer will not be able to perceive a continuity of the element and the motion illusion will fail. If however, the same scene contains an element of interest such as a person running that moves with the pan, the viewer will tend not to perceive the insufficient representation of the background motion because his attention is focused on the image element with the highest information content. The viewing conventions established by motion picture photography also lead to the acceptance of certain motion artifacts as part of the content, such as the unsteadiness caused by a handheld camera, which may be used to suggest a very intimate point-of view.

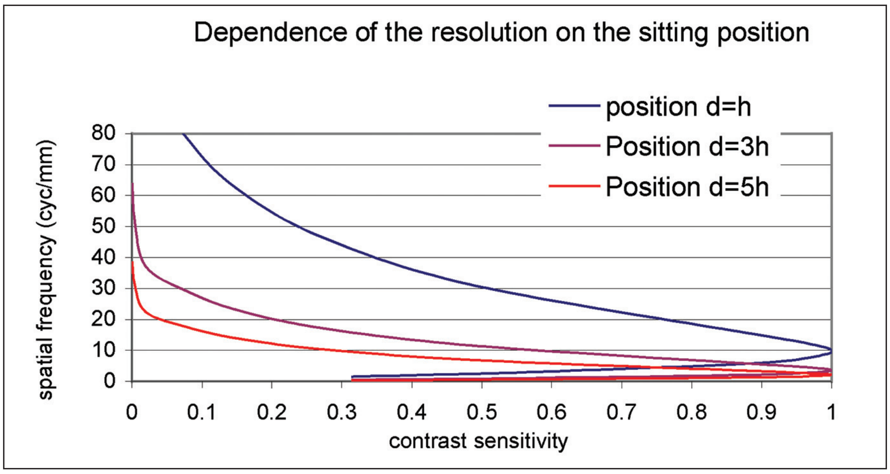

Figure 4. Dependence of the resolution on the sitting position.

Influencing Visual Parameters in an Electronic Image Capture System

As mentioned above, one of the design goals of an electronic image capture system is to give the cinematographer the ability to create images using the visual language that has been historically established. At the same time, the system should provide enough freedom for creation of entirely new image impressions. This is only possible by considering the image parameters in terms of the creative aspects discussed above and providing the means to influence them appropriately within the design of the image capture system.

Resolution

To ensure that the imaging characteristics of a digital capture system correspond to those of film-based systems, an essential prerequisite is the ability to use the same photographic lenses. Film-style lenses are designed to project an image onto a planar surface without intermediate optical elements. To preserve the lens quality, the digital capture system must provide the same conditions. Moreover, it is desirable for the imaging sensor to have the same dimensions as the aperture of the film-based system so that the lens will exhibit the same characteristics with regards to depth- of-field.

Given these initial conditions, the digital imaging system can now be optimized with regards to resolution characteristics. Principally, the resolution of the whole camera system is the product of the modulation transfer function of the lenses, of the sensor, and of the filters in front of the sensor. The criteria for an optical optimization of these components are derived from the physiology of the human eye in the cinema-viewing environment. A diagram of the resolution capacity of the human eye at an average screen luminance of 30 cd/m^2 for three sitting positions (distance = h, 3h, 5h with h as the screen height) is shown in Fig. 4.

The following consequences for the resolution calculation of the optical components can be drawn from Fig. 4:

a) The maximal contrast sensitivity of the human eye of 1 is achievable in the range between 2 and 10 cycles/mm. In this range, the MTF-value of the optics has to be as high as possible.

b) The contrast sensitivity of the human eye remains on a good level of being better than 0.5 up to 32 cycles/mm. It is also necessary to keep the MTF-values high in this range.

In Fig. 5, the MTF-function of a theoretical resolution-limited lens at 550 nm and at an aperture k = 2.3 is shown in comparison with a real camera lens of Arnold and Richter (ARRI). It can be observed that the MTF-values of these two lenses are practically identical in the range up to 32 cycles/mm and the difference is very small up to 60 cycles/mm.

It is also known that the aliasing artifacts should limit the resolution of a digital camera, because the pixels are periodically arranged on the sensor. For a pixel pitch of about 8 µm, the Nyquist frequency is 62.5 cycles/mm, beyond which a structure of the object can cause aliasing. Referring to aspect, the developers of a digital camera have to make the following compromises:

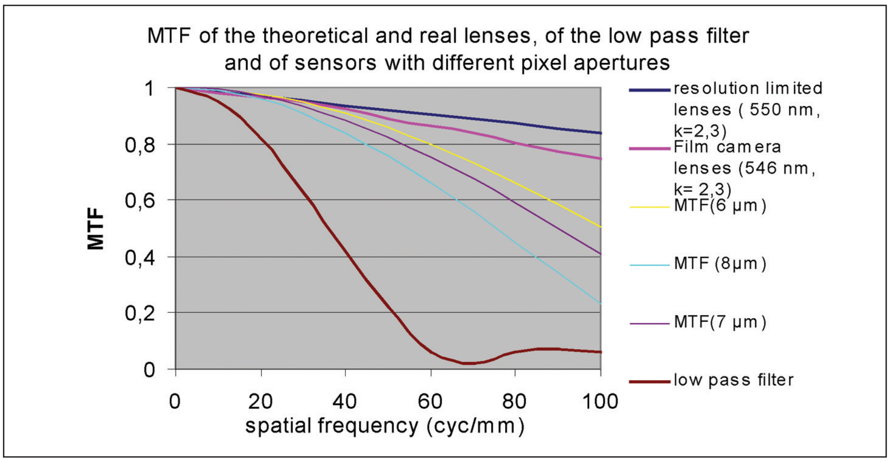

Figure 5. MTF of the theoretical and real lenses, of the low-pass filter and of sensors with different apertures.

a) All very good lenses have a relatively high MTF-value beyond 60 to 80 cycles/mm, so the potential for alias from the lens side is high.

b) With a smaller pixel aperture, it is possible to achieve high sensor-MTF but this also leads to a low signal-to-noise ratio (SNR).

c) For a conservative design of the low-pass filter, it is possible to reduce the artifacts to a minimum, but in this case the MTF in the range about 30 cycles/mm is relatively low and the image is not very sharp.

The optical modulation transfer function of the low-pass filter is realized and the sensor pixel for different apertures is also displayed in Fig. 5. In this diagram, the MTF of the low-pass filter has a minimum in the range between 62 and 100 cycles/mm for minimizing the aliasing.

By means of all optimized measures built in the ARRI camera, it is possible for the MTF of this camera to be higher than other existing HDTV image systems across the useful spatial frequency range (Fig. 6).

Color Representation

The optical path of the ARRI digital camera consists of:

- The camera lens with the spectral transmittance $\tau_{lens}(\lambda)$
- The optical filters (IR-cut-off filters, low-pass filters, anti-reflecting filters) with the spectral transmittance $\tau_{filter}(\lambda)$
- The color dye layers on the CMOS-sensor pixel with the spectral transmittance $\tau_{dye}(\lambda)$
- The silicon CMOS-pixel with the absolute spectral response $S_{pixel}(\lambda)$

Because all components mentioned above are linear, the absolute spectral response of the whole camera can be formulated as follows:

$$S_{camera}(\lambda) = \tau_{lens}(\lambda) . \tau_{filter}(\lambda) . \tau_{dye}(\lambda).S_{pixel}(\lambda)$$

The spectral response is displayed in Fig. 7. In the filter package, the IR cutoff filter and stray-light-reducing filter are built in, so that high-light ghosts can be minimized. This is useful in cases where the camera is facing the sun or high-intensity light sources on sets.

The spectral response of the blue channel below 450 nm and the red channel longer than 600 nm was optimized for matching to the human eye response. However, in general, the camera spectral responses of the three channels are not identical to those of the human eye. The consequence is that the camera RGB signals are not proportional to the perceptual attributes of the human vision. The general aim of the color reproduction of an Arri digital camera in combination with an HDTV-monitor is to match the color appearance of the monitor images to the objects in front of

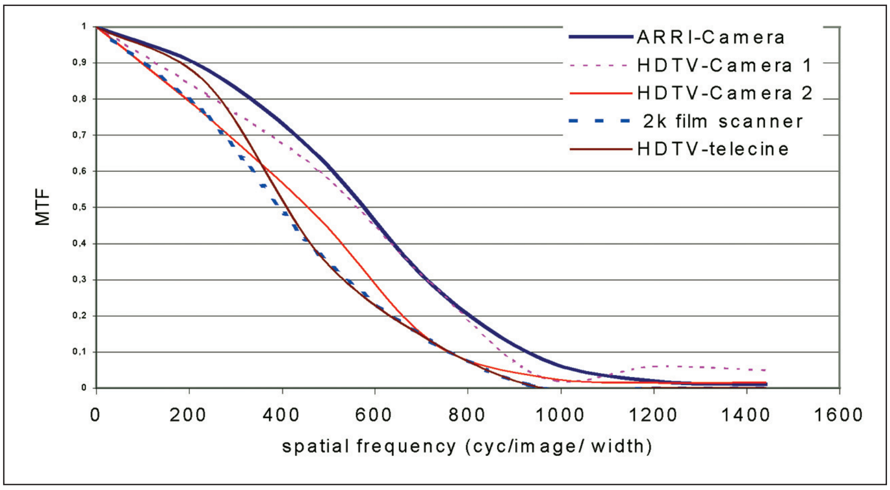

Figure 6. MTF of different high-definition imaging systems.

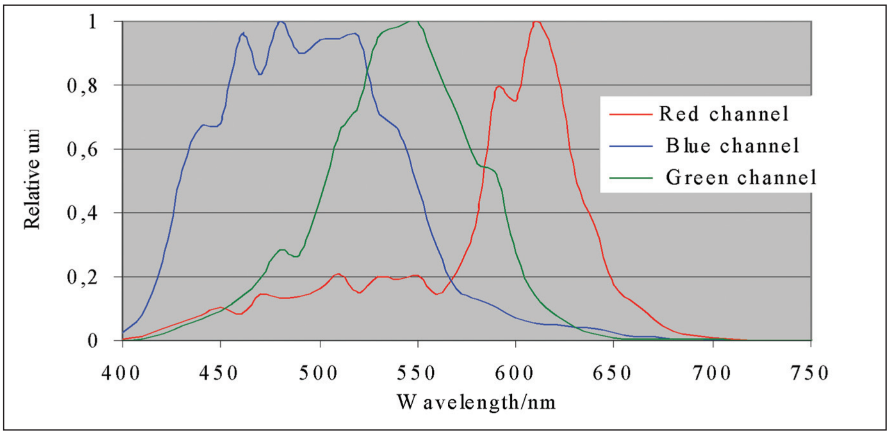

Figure 7. The relative spectral response of the ARRI digital camera.

the camera, as described in Fig. 8.

In order to make the color appearance of the monitor image identical to color appearance on the set scene, it is necessary to characterize the color reproduction features of both the camera and the monitor. This process is called color management for the chain camera-monitor. With the characterizing results, a 3-D Lookup table (LUT) or a nonlinear polynomial function relating the object colors and the RGB-camera signal can be determined and used for the camera.

Dynamic Range

The dynamic range depends on the maximal capacity (full-well capacity) of the sensor and on the noise behavior of the sensor and the signal processing electronics. In general, the noise level depends on the semiconductor sensor process and on the temperature of the sensor. Therefore, in order to reduce the noise level (kTC-noise—which is a random component in the photo signal of the CMOS sensor that originates from the thermodynamic uncertainty of the charge stored on a capacitor), one measure is to cool the sensor to a reasonable temperature, which can be a little greater than the environment temperature.

The other measure is to increase the effective light-sensitive diode area. This is possible by increasing the effective aperture of the pixel and the fill-factor. By increasing the diode area, both the shot noise and kTC-noise can be reduced.

Principally, one can achieve a dynamic range of 60 to 62 dB with the two measures mentioned above. There are further means for increasing dynamic range, which can be implemented in a CMOS-camera

Correlated Double Sampling (CDS)

If the sensor is free from the rotating mirror, an exposure can be taken and the electrical charges are collected in the pixel capacitor. If the rotating mirror is completely in front of the sensor, the sensor is free from the incoming light (dark phase), allowing two possibilities:

- Without CDS: only the charges are read-out and after this dark phase time, a reset is made to set the capacitor onto the level before exposure has begun.
- With CDS: in the dark phase, the capacitor of the exposed image (light image) is first read-out, then the circuit is reset (with some reset noise) and a dark image is taken. After this, the sum of the reset noise and the dark image is read-out. All actions described above are made in the dark phase. The effective image is then generated as the difference between the light image and the sum of the reset noise and the dark image. Therefore, an extension in the dynamic range of about 6 dB (one lens stop) can be achieved (Fig. 9).

Multiple Exposure

The aim of the dynamic range extension is not only

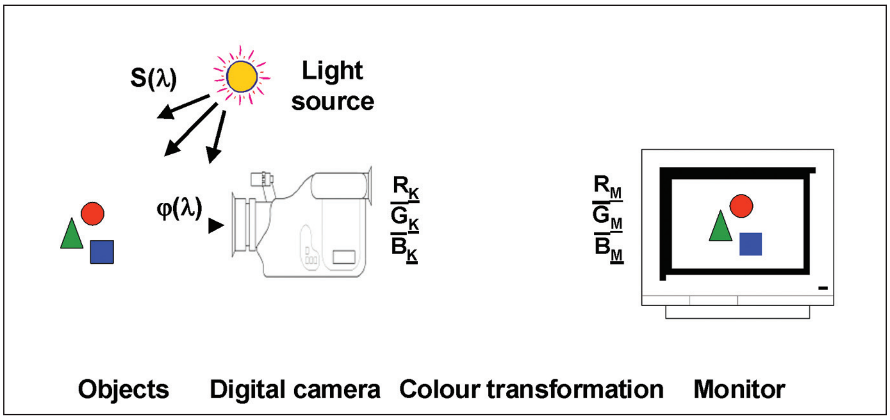

Figure 8. Color transformation in the capture and display path.

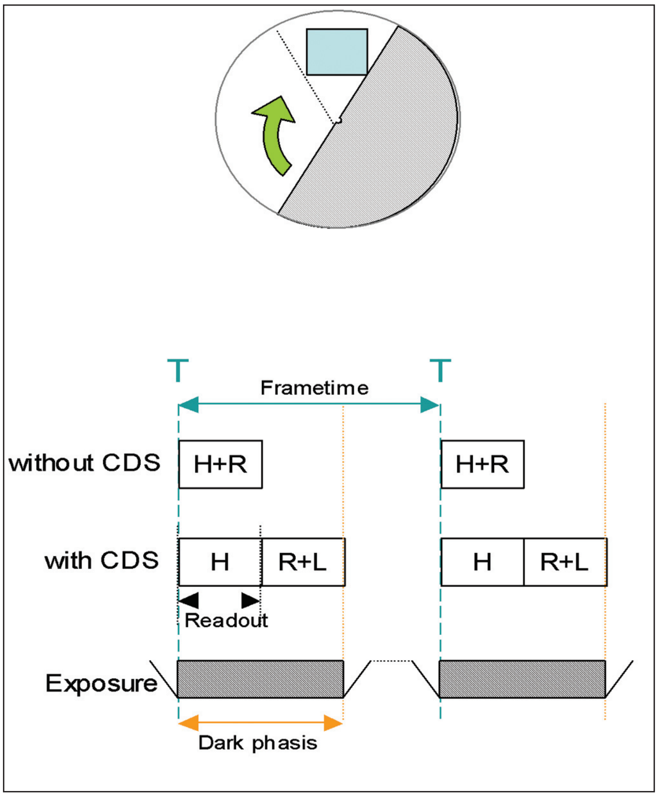

Figure 9. Correlated Double Sampling (CDS)

the extension in the dark range. It is desired to have more image information in the light range with intense light sources. This is possible with a CMOS-sensor with multiple exposures, as shown in Fig. 10.

- From the total available frame time T, a short time T1 (usually T1 < 0.1 T) is taken for an exposure and the image is then read out and reset. Because the time is short, only areas on the object plane with high brightness deliver useful information.
- An additional exposure with a long exposure time T2 is made and the image is read-out and reset. In this relatively long exposure, object areas with relatively low brightness deliver information in the right range and areas with high brightness deliver signals in overflow.

From the two images, an image calculation can be done to achieve an image with information both in the dark and in the light object areas. The ratio T2/T1 determined the dynamic extension factor, which can be more than 10 dB.

Motion Representation

To be able to offer the same creative options in terms of motion representation as a conventional film-based system, a digital capture system must provide control over the frame rate and exposure time.

Frame rates between 1 and 150 frames/sec are achievable with standard production film cameras. This range can even be extended with specialized cameras or accessories. In addition, the frame rate can be varied while shooting. To achieve similar control in a digital capture system, the data-handling rate must first be addressed.

The prototype digital camera utilizes a sensor with a pixel count of up to 6 million pixels. At a frame rate of 150 frames/sec, a read-out rate of 900 MHz would be necessary. As this is hardly feasible, the sensor must incorporate the parallel read-out channel to enable higher frame rates. The sensor is designed with 32 parallel channels, each clocked at 20 MHz. The parallel data handling was one of the main reasons to choose CMOS technology for the image sensor in the digital camera.

Although the parallel data handling does allow for a much higher frame rate at a manageable clock rate, the top rate achievable by film cameras has not yet been matched. To improve the frame rate performance, another design feature of the sensor can be employed. Because the sensor is based on CMOS technology, it is possible to individually address pixels. Because of this feature, the frame size and the pixel count per image can be varied. If a lower pixel count can be tolerated, a proportionately higher frame rate is achievable.

Next to the frame rate, control of the exposure time, and the time between exposures is necessary to produce specific motion representation effects. Short

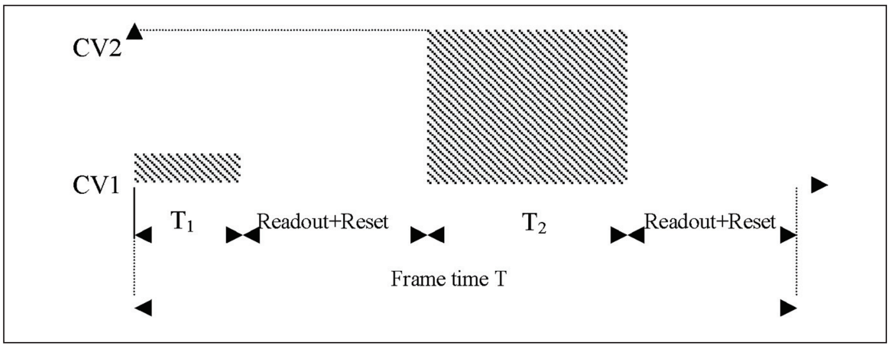

Figure 10. Multiple exposure.

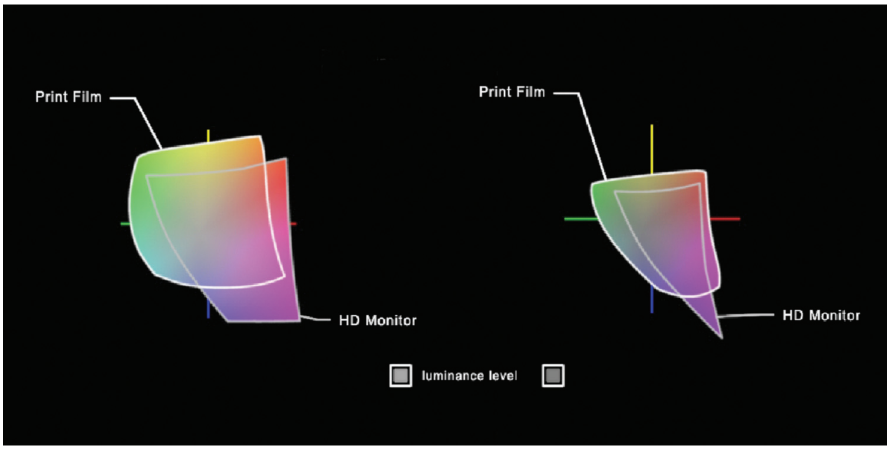

Figure 15. Comparison of film and HD-monitor gamut at different levels of brightness.

Figure 16. CMS is used as 3-D preview LUT to modify the display of logarithmic images in the grading session.

green, and blue, and Xr Zb are the tristimuli of the primary spectrums. Therefore the color gamut, the volume of all possible colors of a monitor or a DLP projector, is a linear distorted cuboid with straight edges in the XYZ-space (Fig. 13).

Color reproduction on film is totally different. The light from the projection lamp is partly absorbed by the color layers of the film material. As the spectral transmission of the color layer arises from the amount of dye "c" and the spectral characteristic "$\epsilon(\lambda)$" according to $T(\lambda)=\exp(-c\epsilon(\lambda))$, the form of the spectrum, and thus the chromaticity changes with the lightness. With the form of the spectrum, the maximums of the spectrum changes accordingly. The combination of different color layers results in a multiplicative color mixing. Figure 14 shows that the gamut of the film in the XYZ-diagram is a bended body. No linear transformation can convert this into the straight body of the video gamut.

A 3-D Lookup table can do the nonlinear transformation between the two color gamuts. The remaining problem is the size of the color gamut. Each color gamut contains colors that are not reproducible in the other color gamut. This means that the number of producible colors is not the same in each gamut. However, one gamut does not completely enclose the other. Depending on the lightness and the color, the monitor gamut is sometimes bigger than the film gamut and sometimes smaller (Fig. 15).

This is why—next to the accuracy of the transformation—the handling of out-of-gamut colors is a big challenge to a color management system for the film post-production.

Color Management with ICC Profiles

Color management systems (CMS) often use the Lab-values (L=lightness; a=red-green axis; b=blue-yellow axis). They are based on the tristimuli, but are more suitable, as the color differences fit better to the visual perception of the eye. Also, Lab values are always relative to a certain white point, which is important as the white point for film and video can be different, but as the chromatic adaption of the eye can compensate for that, the translation must not be done by the color management system. The main idea in the ICC (International Color Consortium) standard is that each device is profiled separately. The profile is used to transform the RGB values into Lab and utilizes a standardized file format. The transformation in the profile is saved as a 3-D Lookup table, which is based on measurements.

Therefore, for the transformation from monitor to film, two profiles are needed. The monitor profile contains the characteristic of the monitor, as well as the calibration and the surrounding light conditions. The ICC profile for the film characterizes the complete chain, containing, film recording, laboratory, film print,

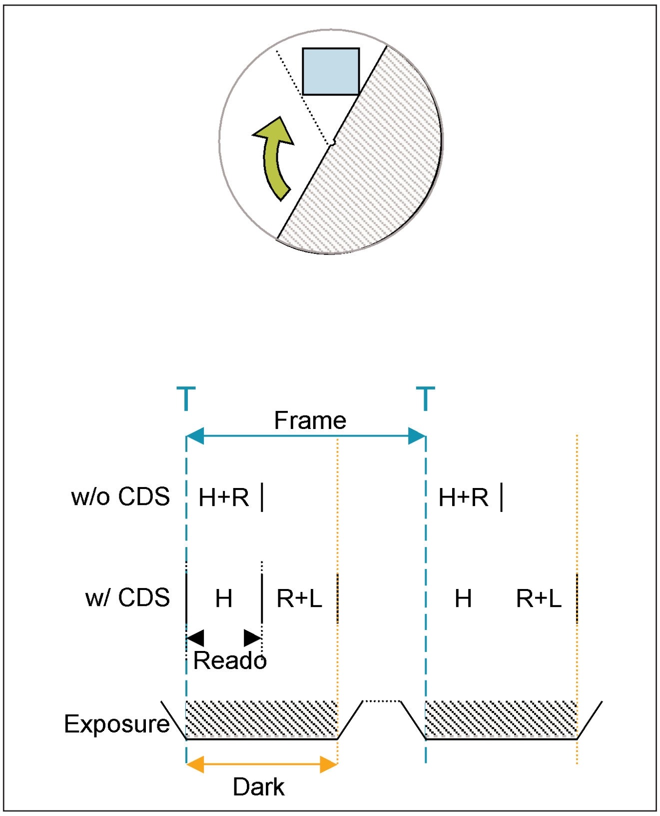

Figure 11. Exposure control with a mechanical shutter.

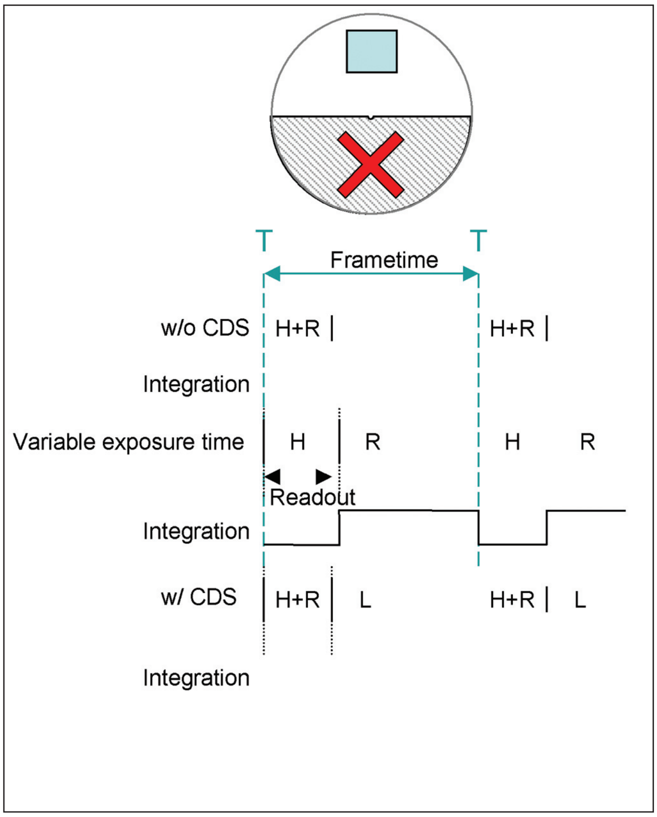

Figure 12. Exposure control with an electronic shutter.

exposure time, together with long intervals between the individual images will lead to a "stroboscopic" motion effect. When used creatively, this effect can be employed to suggest very hectic action. Conversely, long exposure times with short intervals between images will cause details in the individual images to be blurred when moved and lead to a generally more fluid impression of motion.

The ARRI digital camera offers two possibilities of controlling these parameters. In the first mode, the camera operates with a conventional rotating shutter as employed in film-based camera systems. At a given frame rate, the exposure time is proportional to the angle of the open sector of the shutter. This angle can be varied between 11° and 180°, thus allowing exposure times between 0.03 x (1/frame rate) and 0.5 + (1/frame rate).

Although this method corresponds exactly to the motion capture characteristics employed in a film-based camera, it is in some respects limiting for a digital capture system. Firstly, read-out of the sensor can only be carried out when the imaging area has been completely covered by the mechanical shutter, otherwise the integration time of the individual pixels would not be the same. This would lead to exposure differences across the image. Because of this requirement, the time available for the read-out of the sensor is less than the time of one image cycle minus the exposure time, as the time required for the shutter to sweep across the image area must also be taken into account (Fig. 11). This limits the maximum frame rate, especially when the method for increasing dynamic range described above are employed.

Secondly, by principle, the mechanical shutter has a fixed maximum exposure time and with it a fixed minimum time between exposures. With the design employed in the prototype, the longest exposure time corresponds to half of the image cycle.

To counter both these limitations, the camera prototype can also operate in a mode without the mechanical shutter. Although this introduces substantial drawbacks with regards to handling, by deactivating the optical reflex viewing function, this mode allows the sensor to be read out continuously (Fig. 12). The maximum exposure time can thus equal the image cycle with the time between images being mathematically

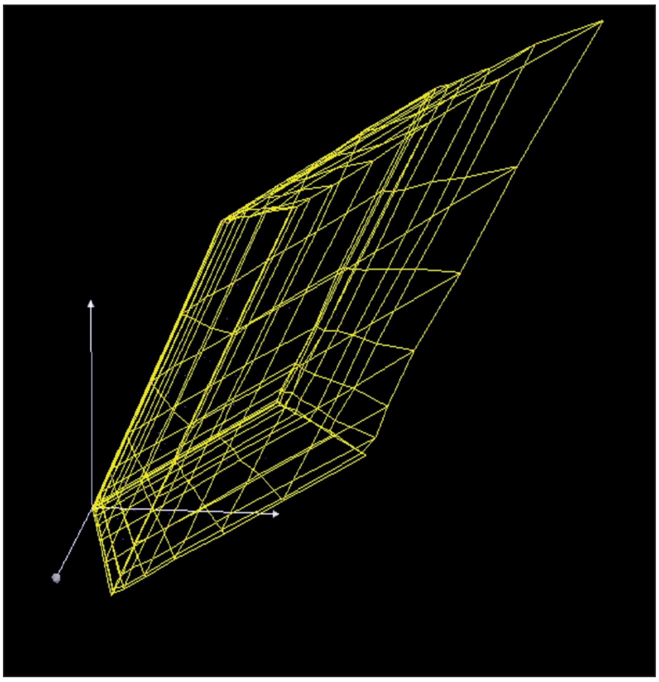

Figure 13. Monitor color gamut in XYZ.

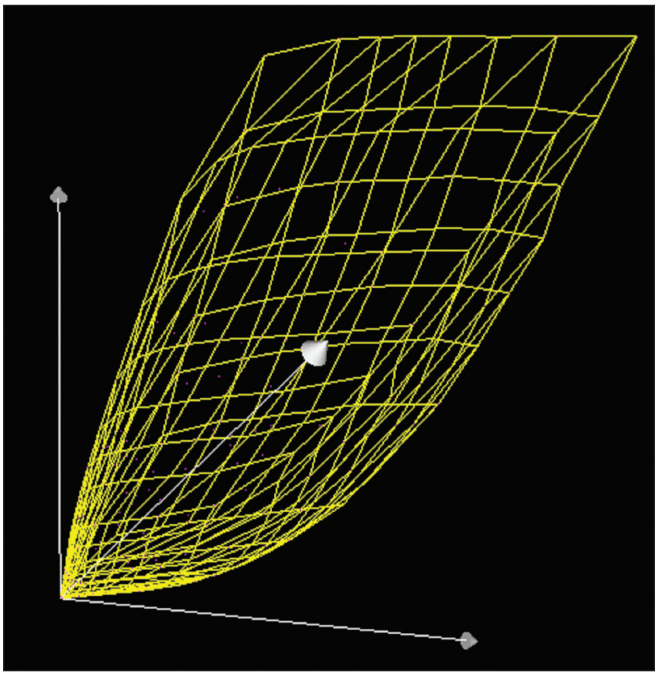

Figure 14. Film color gamut in XYZ.

reduced to zero. The time available for reading out the image pixels corresponds to 1/frame rate.

Digital Intermediate

Another form of a hybrid workflow is the digital intermediate. This means that the acquisition and/or the distribution is analog (film-based) and the post-production is done digitally. As in this case, the color grading is usually done in the digital area—either on a high-class monitor or a digital projector. It is very important to make sure that the colors will look the same in the final result in the film projection as was decided on the grading suite. The following chapter will explain why this is not self-evident and how it can be achieved.

Differences in Color Reproduction for Film and Video

Color gamuts of film and video are not identical. A closer examination of their respective properties reveals that a transformation between them has to be nonlinear. This transformation will usually be done via a so called 3-D Lookup table.

Measurement of Colors

The first step for the color space transformation is the measurement of the colors. Color is not a physical, but a physiological quantity, thus the color perception depends on the spectrum of the light that meets the color receptors in the human eye. There are three different color receptors in the eye, so it is possible to describe the complete color perception with three values, which are called the tristimuli. These values were standardized by the CIE (Commision Internationale de l´Éclairage) in 1931. Tristimuli values X,Y,Z are calculated from the spectral distribution E(λ) of a visual stimulus by spectrally integrating and weighing with the color matching functions x(λ), y(λ), and z(λ).

$$X=\int x(\lambda)E(\lambda)d\lambda \quad Y=\int y(\lambda)E(\lambda)d\lambda \quad Z=\int z(\lambda)E(\lambda)d\lambda$$

Comparison Between Film and Video Color Gamut

The color space of a monitor or a Digital Light Processing (DLP) projector is characterized by an additive color mixing, because all colors arise from the combination of the emission spectrum of the three phosphors (monitor) or the color filters in the beam path (projector). All colors are therefore a combination of the tristimuli of the three primary colors.

$$E(\lambda)=rE_r(\lambda)+gE_g(\lambda)+bE_b(\lambda) \Rightarrow$$

$$X=\int x(\lambda)E(\lambda)d\lambda = rX_r+gX_g+bZ_b$$

$$Y=\int y(\lambda)E(\lambda)d\lambda = rY_r+gY_g+bZ_b$$

$$Z=\int z(\lambda)E(\lambda)d\lambda = rZ_r+gZ_g+bZ_b$$

Where $E_r(\lambda),E_g(\lambda),E_b(\lambda)$ are the primary spectra of red, and projection. All parameters in this chain, such as negative material, negative calibration, print material, print calibration, type of film recorder, projection lamp, and screen, are responsible for the measured color. To get the best color reproduction, the conditions of the measurement have to be as close as possible to the real life conditions. Therefore, it is very important to control the complete laboratory process very strictly and have a film projection that is close to the SMPTE specifications. For various film materials, different profiles are necessary.

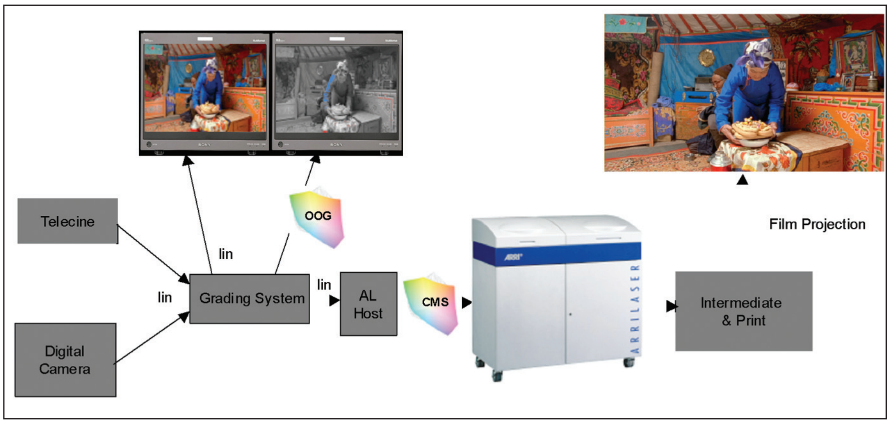

Figure 17. CMS is used to modify the linear files in the Arrilaser prior to recording. Out-of-gamut (OOG) LUT is applied in the grading session to verify the color gamut.

Use of 3-D Lookup Tables in the Digital Intermediate Process

The 3-D Lookup table can be used in the Digital Intermediate process at different stages. The preferable workflow depends on the project.

Logarithmic Workflow

In case of the logarithmic workflow the incoming data will be logarithmic. Most likely the acquisition is done on film and the data are scanned with a real film scanner. The 3-D Lookup table is then used to change the display on the monitor or the DLP projector in the way that the colors will appear in the film projection. As the logarithmic file formats represent the densities on the film in the best way, in this case the data will not be changed at all, and only their look on the monitor is modified. The complete film gamut can be used, as the film color space is never left. The 3-D Lookup table can be loaded into the color correction system or in the DLP projector directly. The demands on the color correction system are very high, as the 3-D Lookup table needs to be applied to the data in realtime (Fig. 16).

Linear Workflow

If the original data came from a digital camera or is scanned by a telecine or the main purpose of the material is for video or TV, the post-production will usually be done with linear data. The unmodified images are displayed on the monitor or on the DLP projector for the color correction. In this case, the images will be converted by the 3-D Lookup table on the output film. This can be done directly in the film recorder and does not need to be in realtime. The colors in the film projection will then be identical to the colors on the monitor. In this workflow, it is important to take care of the colors that can be displayed on the monitor but not on the film. Those out-of-gamut colors cannot be recorded without changes, as they do not exist on film.

By default, these colors would be hard-clipped into the recorder gamut. This would lead to a detail loss in those areas. To smoothly clip these colors, a soft clipping needs to be used, which compresses the monitor gamut in the highly saturated areas. It should be noted, however, that the use of soft clipping is a compromise that will result in less-than-ideal color reproduction. Therefore, it is best to avoid out-of-gamut colors in the images from the beginning. A 3-D Lookup table, which is used as an out-of-gamut indication, should be used in the grading session to warn the colorist (Fig. 17).

Source Material Equalization

Often, facilities have to work with scanned material that originates from different sources such as digital cameras, telecines, and scanners. This results in differences in resolution, color appearance, and dynamic range, and complicates working with intermixed materials. Although resolution-independent grading systems have been established in the past years, and gradation adaption can be achieved using proper one-dimensional LUTs, differences in color still need attention.

They are caused by different spectral characteristics of the illumination systems and different spectral sensitives of the sensors. While a simple matrix might be suitable in some special cases, the more general approach of 3-D LUTs is used here also. By measuring the same set of test patches exposed on camera negative and scanned on the various scanners involved, the 3-D LUT can be calculated from the measured data. It transforms the RGB data measured on one scanner to those measured on another scanner. Again, ICC profiles allow one to store 3-D LUTs in a standardized file format as a so called device linked profile. A colorimetric analysis is then performed on the images, using a calibrated display to judge the differences in color and gamma. The goal is to derive a color management that is able to match between the various scanner systems available in the market.

Conclusion

This paper has reviewed the factors affecting image quality in a hybrid production environment. Issues relating to resolution, depths of field, dynamic range, and color management have been discussed. As with many tasks, basic understanding of the technology and careful attention can provide a working solution.

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