Brightness, Color, Contrast and Resolution – Criteria for High Quality Digital Imaging

Christhard Deter
Jenoptik LDT GmbH

Volkmar Schorcht
Carl Zeiss
Planetarium Division

One image is not the same as another: this is an obvious statement that needs no elaboration. But when it comes to explaining why, given the same projector parameters, the visual impression can vary so enormously, then we have to bring science to our aid. The buying public is wooed with pixel numbers, contrast and brightness levels. This article is an attempt to describe what these factors mean for full-dome projection in practice.

Projector parameters are defined by specific design solutions and tests. They cannot, however, provide reliable information about the visual quality of the projected image. To establish the connection between the technical parameters and visual quality, we have to consider the criteria for visual perception. In other words, we have to examine how a projected image is perceived by the human eye.

The quality of a projected image depends on:

- *Brightness* (luminous density)
- *Color* (the color gamut)
- *Contrast* (difference between light and dark)
- *Resolution* (angular resolution)

A number of other factors affect the visual quality, such as image steadiness (or flicker), optical imaging properties such as sharpness or color distortion, and technically induced artifacts such as trailing and ghosting. The latter criteria are only of secondary concern here.

The eye experiences image quality as the result of a combination of factors. It cannot distinguish them individually. In other words, a single projector criterion says nothing about the quality of the image.

Brightness

The measure of image brightness is *luminous density*, which is derived from the light flux of the projector, the spatial angle covered and the illuminated surface. The type of light source – whether halogen lamp, CRT tube, laser etc. – is immaterial.

The eye adjusts to varying ambient brightness levels, so it cannot assess brightnesses in absolute terms. On the other hand its perception of adjacent brightness differences is highly developed. Astronomers take advantage of this capability to determine visually the brightness of variable stars.

However, the ability of the eye to perceive brightness depends not only on luminous density. High contrast images are perceived as brighter than low contrast ones. The same applies to color saturation. Comparative measurements and subjective brightness tests with an LCD projector and a laser projector (LDT) at Carl Zeiss confirm this. As we might expect, with a white image the double luminous density of the LCD projector was perceived as much brighter than the LDT, but high contrast images in strong colors were perceived as being more or less equally bright.

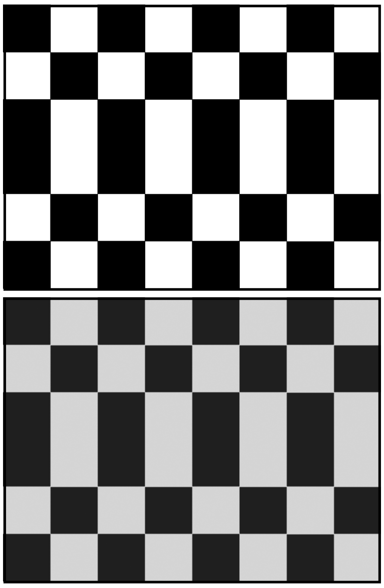

Fig. 1: The overall brightness of both test images is the same. But the top one seems brighter because it has a higher contrast.

Brightness affects the visual acuity – normally defined in terms of *angular acuity*. That is the angular distance between two points that are still separable by the human eye. Visual acuity, i.e. the resolving power of the eye, declines with decreasing brightness. With the brightness range of 3 cd/m² encountered in dome projection we are already using scoptic vision (night vision).

Color

We experience light of differing frequencies in the visible spectrum as colors. A projector can always only generate a limited spectrum of all possible colors (the color space). The crucial factors are the properties of the light source and the type of color filtering or mixing used.

Our color perception is stimulated by a combination of the three primary colors – red, green and blue. A specific mix of the three produces white. The various light sources for projectors create a virtually white light, from which the colors are filtered out. The primary colors are therefore broadband colors and the color reproduction is less saturated. Because of the nature of laser light, they are extremely narrow-

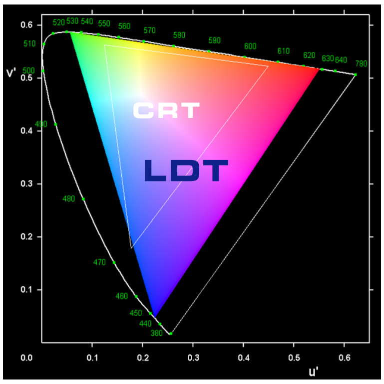

Fig. 2: The "corners" (primary valencies) of the laser color triangle of LDT are in singular value wavelengths, that is pure, unmixed colors of high saturation compared with other projection technologies such as CRT projectors.

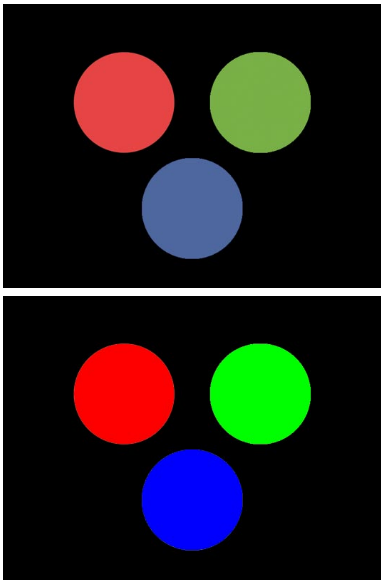

Fig. 3: Offset printing cannot reproduce the full distinction between color spaces. Laser colors are ruled out. In the bottom image the primary colors are more heavily saturated, making a more brilliant impression.

band and spectrally pure. The laser color space is much larger and it includes that of conventional projectors. It also includes "artificial" colors that do not occur in nature. The eye perceives them as highly saturated. In the color triangle they are further away from the white point than the primary colors of conventional projectors. Images containing highly saturated colors like this are perceived brighter than those with conventional colors and make a particularly brilliant effect.

Contrast

Contrast describes differences in brightness, i.e. variations in luminous density. These variations may be local (parallel) or vary over time (consecutive). An image of uniform local brightness that does not change in time shows *no* contrast. Or to put it another way: an image consisting of 100,000 pixels of uniform brightness and color is similar to an image consisting of a single - big - pixel.

Contrast data refers to the *maximum difference* between bright and dark. So the contrast ratio says nothing about the maximum brightness, nor about the brightness of the residual light (dark light, sometimes also called "black light"). The greater the contrast ratio, the less the residual light. Tests are normally based on the on-off contrast, which describes the ratio of minimum to maximum luminous density for homogeneous images alternating in succession. Typical values are:

- LCD projector 1 : 250 to 1 : 500
- DLP projector 1 : 300 to 1 : 1000
- CRT projector 1 : 1000
- D-ILA projector 1 : 1000
- LDT laser projector 1 : 50 000

The extreme value of the LDT projector is due to the fact that when the signal is switched off (black), there is virtually no residual light at all. Black is black.

The contrast within the image (local contrast) is equally crucial for its visual impact. How great are the differences in luminous density in closely proximate areas, on the threshold between individual pixels (the pixel contrast)? Tests can be carried out on alternating black and white lines with the width of a pixel.

LCD and micromechanical projectors use optical imaging systems. The image-producing elements reveal mechanical structures, e.g. the boundaries between the LCD cells or the edges of the micromirrors, which cause contrast reducing and other negative diffraction effects. Black lightens to gray over the whole image format.

Diffraction effects due to the wave characteristic of light and the restricted imaging quality of the optics result in "optical blurring" of the differences in luminous density. Consequently, the contrast level, and with it the sharpness, is reduced.

Resolution

Resolution is typically defined as the number of image points a projector will reproduce: it specifies the number of addressable pixels (the product of the number of columns and the number of lines) in the image projected. Data projectors are normally based on standardized formats (see box). The higher the number of pixels on a uniform projection surface, the higher the resolution.

A higher resolution can only help improve the visual impression if the individual image points produce distinguishable pictorial information for the eye at the given viewing distance. This requires a correspondingly high quality of optical imaging and high contrast. Resolution and pixel contrast together determine the image sharpness.

The following test data for contrast – tests measured the difference in luminous density between black and white columns at constant conditions – clearly shows the difference in the technologies:

- CRT (BARCO 808): 4%
- LDT (G1, XGA): 35%

The data demonstrates how dramatically the pixel contrast in the image changes compared with the on-off contrast. It also dem-

Standardized formats for video and data projectors

Format	Col.	Lines	Aspect r.
NTSC		525	4:3
PAL		625	4:3
HDTV	1920	1080	16:9
VGA	640	480	4:3
SVGA	800	600	4:3
XGA	1024	768	4:3
SXGA	1280	1024	5:4
UXGA	1600	1200	4:3
QXGA	2048	1536	4:3

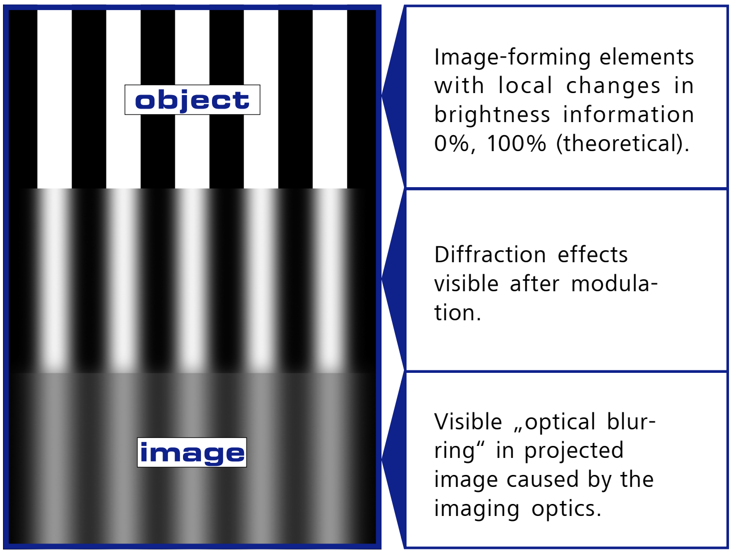

Fig. 4:
The optical transfer function of conventional projection methods reduces the actual resolution considerably.

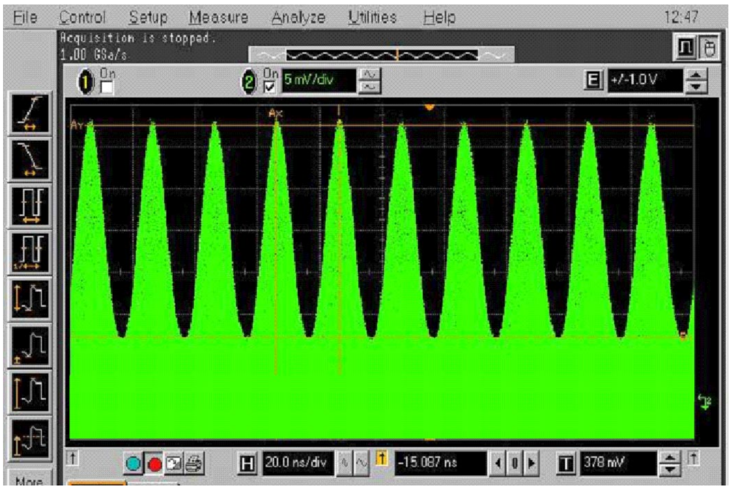

Fig. 5:
Test showing the real column contrast of an LDT projector. The difference in luminous density is more than 50%.

onstrates that the laser projector (LDT) achieves almost ten times the contrast level for the viewer compared with CRT projectors.

If dome projection is to achieve the resolving capacity of the eye, it can only do so using multi-channel projection. Single channel systems do not produce a sufficient number of pixels and require fisheye lenses whose imaging properties cannot reproduce the pixels perfectly.

The resolution actually achieved on a dome is lower than the nominal resolution, because the optical transfer function results in resolution losses. These may be significant, as illustrated in Fig. 4. The actual image sharpness, therefore, is not determined by the number of pixels but by the modulation transfer function. The latter takes into account the diffraction effects and the optical imaging quality.

If we want to compare the resolutions of different systems, we have to consider not only the nominal projector resolutions but the edge blended zones which are wasted. With a seven-channel system with SXGA projectors and about 25% edge blending, only about 6.8 million pixels are used, not 9.1 million.

The same applies to single projectors with fisheye systems. An SXGA projector produces 1.3 million pixels. If the maximum possible circular segment is used for dome projection, effectively only 0.8 million pixels are available for the dome.

Geometry

From the geometrical point of view dome projection means converting a right angle into a circle, or to be more precise, into a hemisphere. Projectors with only one optical system create a circular section of their standard format (e.g. SXGA). This means 37% of the projector resources are lost. One alternative is to utilize the full width of the image-forming element and cut off one segment. This leaves just 15% unused but one section of the dome is lost.

In any case the square pixels are severely distorted at their periphery as a result of projecting onto a sphere.

Even with multi-channel solutions the pixels are distorted by the oblique angle of projection and the correction for the sphere. With a laser projector the distortion is not apparent; thanks to the scan technology, individual pixels are not reproduced. It is a different story with DLP systems. Here the pixel structures are maintained and with them the distortion.

All projection imaging systems – and that means all of them except LDT projectors – require focusing. With multi-channel installations the depth of focus and convergence setting are not sufficient to achieve a sharp image right into the corners with oblique projection angles. With LDT projectors, however, you can position them in such a way where imaging methods no longer work. The ADLIP installation for IPS 2004 in Valencia is one such case. The projector positions and channel distribution are shown in Fig. 6. All six projectors are in the rear third of the dome and nevertheless cover almost the entire dome surface. It is worth noting the projectors are set up vertically and project in portrait format.

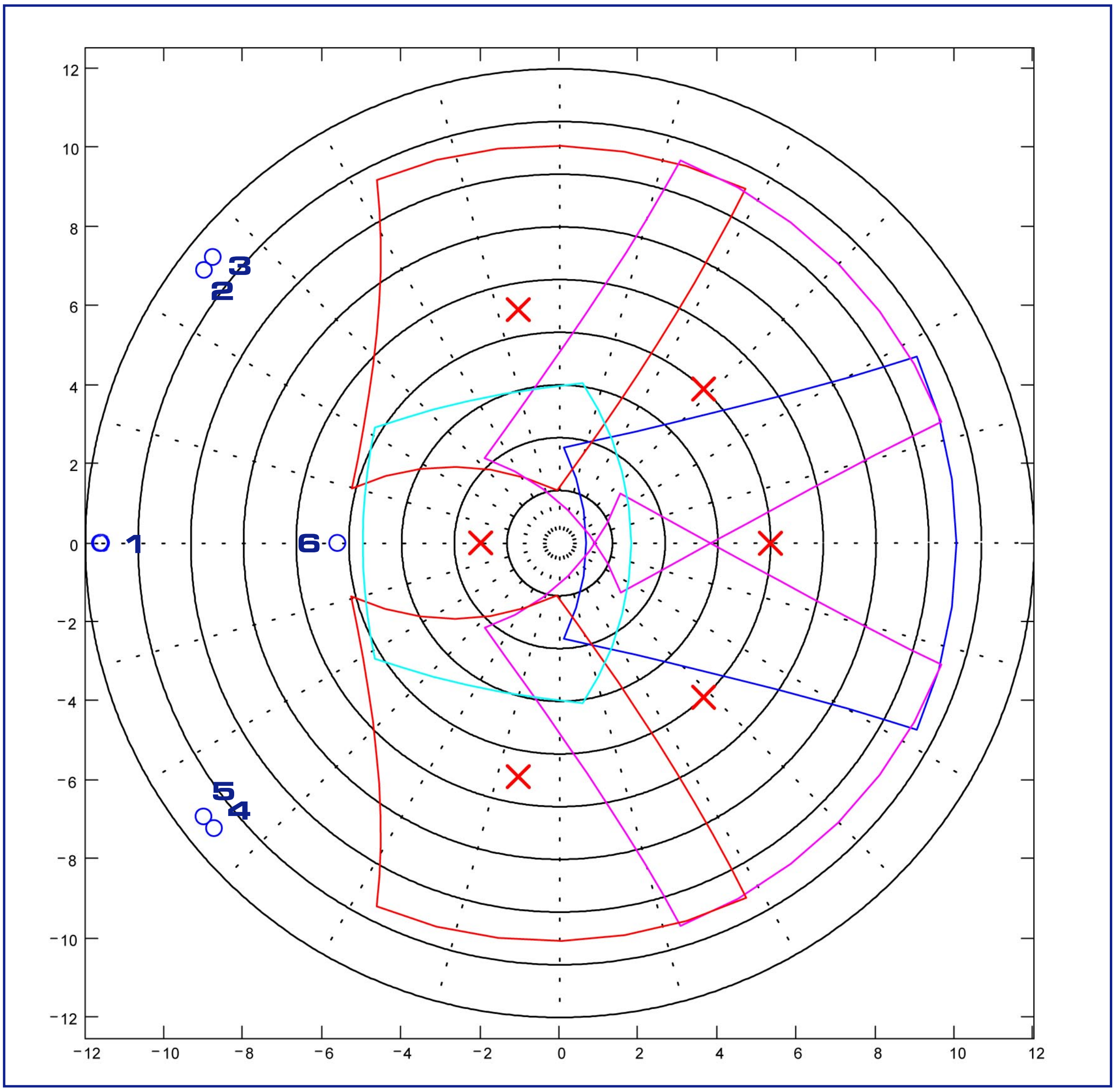

Fig. 6:
ADLIP channel distribution with extreme projector positions in the 24-m dome in Valencia at IPS 2004
Graphic: CZ/Has

Summary

Individual projector parameters do not tell us about the visual quality of an image. The visual impression depends on a combination of all the vital factors. Projectors with the same nominal resolution do not necessarily achieve the same image sharpness.

The nominal pixel number is not enough to enable us to judge the actual image quality. At least as crucial is the pixel contrast, which determines to what extent the pixel information is individually separable by the eye. A nominal pixel number that cannot be resolved by the eye is pointless. The differences between individual projector systems are particularly marked when it comes to small screen font sizes. These are hardly legible with CRT projectors even with UXGA, whereas LDT projectors image fonts sharply with SXGA.

The best visual quality is achieved with laser display technology. Its high level of image sharpness, the result of the scan principle combined with the short pulse time and extremely high pixel contrast, is unmistakable. LDTs achieve this image sharpness even with average pixel numbers, which makes the process of image generation and realtime calculation much easier. Due to its extremely high contrast the LDT projector shows objects in what looks like three dimensions. The eye loses the sense of a projection surface. A planet "falls" from the dome; the International Space Station "floats" above the heads of the spectators.

Theoretical analysis can help us understand the various projection technologies, but it is no substitute for the real thing. Carl Zeiss, therefore, together with Jenoptik LDT, is keeping an ADLIP system available in Jena for demonstration purposes. If you are interested in a demonstration, please get in touch with one of our sales staff or representatives.

Bibliography

Deter, Christhard: Bildqualität von Videoprojektoren, Zusammenhang von technischen Parametern und der Sehempfindung des Nutzers (Equality of video projectors: the connection between technical parameters and the visual perception of the user), Jenoptik LDT GmbH, Gera 2003 (unpublished).

Deter, Andreas: Vorteile der Laser-Display-Technologie (The advantages of Laser Display Technology), Lecture ADP Hamburg 2004