4.5: Important Differences Between Medical Displays and Normal Desktop Displays and Underlying Reasons

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Abstract: *Medical displays obviously require a minimum level of quality that is higher than for consumer displays. This paper will discuss important differences between medical displays and typical desktop displays. Several important display aspects will be analyzed such as display calibration, viewing conditions (ambient light, viewing distance), brightness, bit depth, luminance stabilization and uniformity & spatial noise. For each of those topics we will explain in detail the underlying reasons why these high specifications are necessary.*

Keywords: medical display, specifications, requirements, quality, brightness, contrast, calibration, viewing conditions

Introduction

Functionality of medical displays and normal desktop displays seems very similar: displaying information. In reality however the use case is quite different. Based on a medical display, a medical diagnosis is taken. Before softcopy displays were available, diagnosis was based on hardcopy films where the basic unit was density. With introduction of softcopy displays the visualization hardware changed but the way how to look on it remained the same. Softcopy displays were optimized to mimic hardcopy film as good as possible. For example, the display backlight can be made bluish to keep the blue hardcopy film perception. In the following sections, several display specifications grouped in table 1, will be discussed. Throughout this paper the starting point will always be how human observers really perceive medical images.

Specifications	Normal Display	Medical Display
Mode	Color	Color/Gray
Observers	Everybody	Doctors, Physicians
Calibration	Color management	GSDF
Brightness	<500 cd/m²	400< L <1000 cd/m²
Bit depth	8	10, 12
Contrast	400:1	400:1<C<1000:1
Optical layers	++	+++++
Image.processing	++	++++
Resolution	1-2 Megapixel	2-5 Megapixel

Table 1. Normal vs. medical display specifications

Human observers & viewing conditions

Observer's perception will be analyzed by means of a model of the Human Visual System (HVS). There exist several achromatic and chromatic models of HVS, linear ones based on the Contrast Sensitivity Function (CSF) as *Daly* [1] or *Barten* [2] for achromatic, or *Mullen* [3] for chromatic. More complete models were developed as the VDP by *Daly* [4] or the MOM by *Pattanaik* et al. [5]. But in medical imaging especially the *Barten* model [2] is frequently used and has generally been accepted as reference for achromatic CSF. The *Barten* model is based on experimental data in which the eye is adapted to the luminance value of a uniform background, the state of so-called variable adaptation (see [6] pp.80-81). The model contains all aspects of the contrast threshold detection of sine wave targets surrounded by a luminance equal to the target average luminance, defined as Contrast Threshold Function (CTF). *Barten*'s model of HVS considers neural noise, lateral inhibition (edge enhancement), photon noise, external noise, and limited integration capability, the optical modulation transfer function of the eye, orientation and temporal filtering. Based on this model a unit called Just Noticeable Difference (JND) was defined.

A JND is the luminance difference of a given target under given viewing conditions that the average observer can just perceive. The JND is a statistical, rather than an exact quantity: from trial to trial, the difference that a given person notices will vary somewhat, and it was therefore necessary to conduct many trials in order to determine the exact threshold. The JND usually reported is the difference that a person notices on 50% of trials.

In the context of medical displays a JND means the smallest difference in luminance (between two gray levels) that the average observer can just perceive on the display system. If the luminance difference between two gray levels is larger than one JND then the average observer will be able to discriminate between these two gray levels. On the other hand: if the luminance difference between two gray levels is less than one JND, then the average observer will perceive these two gray levels as being only one level.

Figure 1 shows the luminance (in cd/m²) in function of the JND index as obtained by *Barten*'s model. The eye has a non linear response to luminance. It follows from this figure that in the luminance range of zero cd/m² to 4000 cd/m² there are approximately 1000 JNDs.

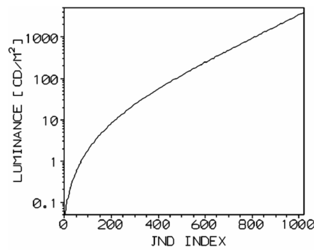

Figure 1. Luminance in function of JND index as defined by *Barten*

This means that a human observer is able to perceive around 1000 different shades of gray over this entire luminance range and in optimal conditions.

Viewing conditions and how to look at medical displays are different from standard displays. Medical habits are coming from hardcopy with a specific low ambient light and viewing distance [8], where the observer looks only on one region of interest. Therefore the quality criterion of uniformity is very important.

Display calibration

Every display system has a specific native curve that describes the luminance behavior (cd/m²) of the display in function of the digital drive level (DDL) or gray level. Typically the native curve of a (medical) LCD display follows an S-shape like curve that differs significantly from the ideal target as shown in figure 1 (this curve is also called the DICOM Grayscale Standard Display Function or GSDF [7]). Therefore if one would just use the display without modification then the perceptual distance between consecutive gray levels (as measured in JNDs) would not be constant. In fact, some gray levels could have a distance smaller than one JND and therefore would not be perceived as being different anymore. Other gray levels could have too large distance resulting in banding artifacts.

To overcome these problems display systems are being calibrated to DICOM GSDF. With a luminance sensor the native curve of the display is measured (typically at the center of the display and for on-axis viewing). Based on the measured curve a lookup table (calibration lookup table) is calculated and configured. This lookup table changes the perceived luminance curve of the display to the required DICOM GSDF curve. This principle is illustrated in figure 2: incoming video data is sent through the calibration lookup table before being sent to the display. This lookup table is configured such that the resulting luminance curve as measured on the display, will match the DICOM GSDF curve as good as possible. A display that is calibrated to the DICOM GSDF standard will have show equal distance between all gray levels as measured in JND space. This equally spacing in JND space is often called perceptual linearization.

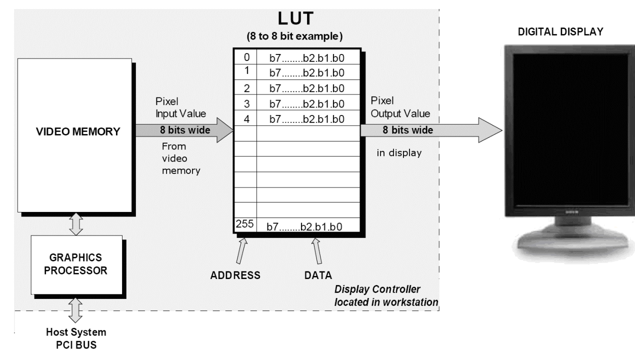

Figure 2. Concept of calibrating medical displays

In addition to calibrating the display often also quality assurance checks are put in place. This means that periodically conformance to DICOM GSDF will be checked with an internal (automatically) or external (manually) luminance measurement device and if necessary the display will be recalibrated.

Brightness

Medical display systems usually have much higher luminance compared to consumer displays. Typical values are between 400 and 1000 cd/m². There are two main reasons why this high brightness is necessary.

Sensitivity of the human eye

First of all the human eye is much more sensitive to small grayscale differences at higher luminance levels. In other words: for a same luminance range (contrast ratio), a human observer can see more subtle differences when the absolute luminance is higher. This becomes clear from figure 3. For a display with black level of 0.2 cd/m² and white level of 100 cd/m² there are around 453 available JNDs. If we increase the backlight luminance so that this same display would have a range between 0.8 cd/m² and 400 cd/m² (same contrast ratio) then there would be already around 720 available JNDs. These levels of luminance correspond to diurnal vision, or to photopic level where only rods in retina play a role.

Ambient light

In addition to higher sensitivity of the eye, a higher display luminance makes it also possible to work in more pleasant environment with higher ambient light levels. When there is ambient light present then part of this light is reflected on the display surface. The effect of this reflected light is proportionally much more important at lower display luminance levels: for low gray values the intensity of the reflected ambient light and the intensity of the light emitted by the display itself, are of the same magnitude. At higher luminance levels however the display emits much more light compared to the reflected ambient light.

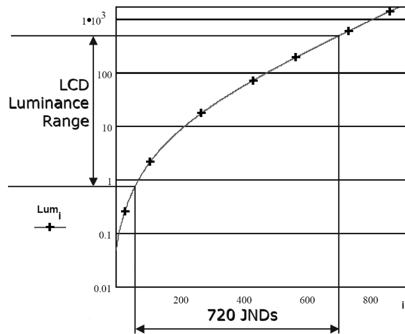

Figure 3. Available JNDs depends on contrast ratio and display brightness

Figure 4 shows the transfer curve of a medical display in dark room and in normal ambient light conditions. Reflected ambient light results into compression of lower gray levels: because of the luminance offset added by the reflected ambient light the differences between low gray level values become extremely small. Moreover ambient light also lowers overall display contrast ratio. Higher display brightness lowers the impact of light reflections and therefore makes it possible to use the display in brighter environment.

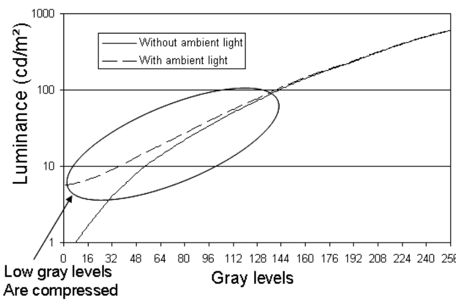

Figure 4. Effect of ambient light on display transfer curve

Bit depth

A display panel can only visualize a finite number of discrete gray levels. Therefore the resulting curve after calibration will only be an approximation of the desired DICOM GSDF curve. Figure 5 shows that there is a so called "quantization error" present. This quantization error results from the fact that only a discrete number of panel gray levels are available (the inherent bit depth of the panel) and therefore the exact desired luminance value can typically not be reached. It is clear that the size of the quantization errors will depend on the luminance difference between consecutive gray levels and therefore on the number of available panel gray levels. Typical nowadays medical LCDs have an inherent bit depth of between 10 and 12 bits (1024 to 4096 gray levels) to guarantee sufficient accuracy. Panel depths of more than 8 bits are usually achieved by means of spatial or temporal dithering.

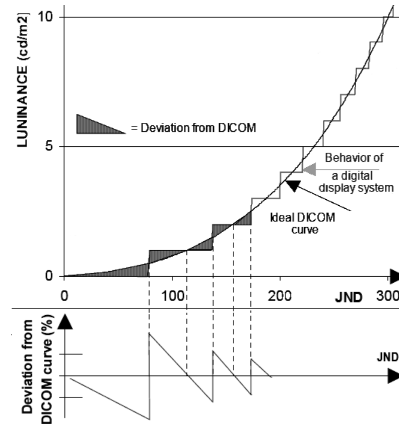

Figure 5. Quantization error due to limited panel bit depth

Luminance and backlight stabilization

Characteristics such as backlight efficiency and LCD panel transmittance decrease over time. Figure 6 shows typical peak luminance for a grayscale medical display system with high brightness backlight system. To guarantee image consistency it is common practice in medical imaging to require that a display system keeps it "calibrated luminance" over its entire lifetime. This calibrated luminance is typically about half of the initial maximum brightness of the display. The backlight of the display therefore will need to be driven in such way that at any time the peak luminance (luminance when full white is shown) equals the chosen predefined value.

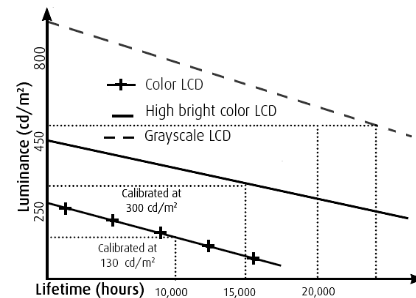

Figure 6. Peak luminance in function of backlight time

To achieve this goal medical displays mostly make use of a built-in luminance sensor as shown in figure 7. This sensor measures in real-time the current luminance value either in the backlight (backlight sensor) or at the front side of the display (front sensor). Corresponding software then calculates the required backlight drive value based on the sensor measurement data. Advantage of using a front side sensor is that not only decreasing of backlight intensity is detected but also all other effects such as changes in the optical properties of LCD (decreased transmittance, browning of the polarizers, …) and any possible problems in the complete image chain (graphical board, lookup tables, …) can be measured and compensated for. An

additional advantage of front-sensor technology is that the sensor can also be used for display calibration and this transparently for the user of the display.

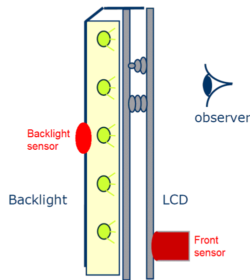

Figure 7. Luminance stabilization using an internal sensor

Uniformity and spatial noise

Medical LCD displays suffer from spatial noise. There are several causes of spatial noise: non-uniformity of the backlight is responsible for the typical luminance fall-off towards the borders of the display. Other causes are LCD cell artifacts causing higher frequency, pixel by pixel variations in the brightness of the display. Such artifacts are caused by tolerances on the storage capacitor of each LCD pixel, non-perfect rubbing of the LCD alignment layer, tolerances in the conductivity of the column and row conductors, varying characteristics of the cell transistors or tolerances in the driver circuits. The superposition of all of these effects results in spatial noise, often also called mura, seen as a fixed, "cloudy" pattern on the LCD.

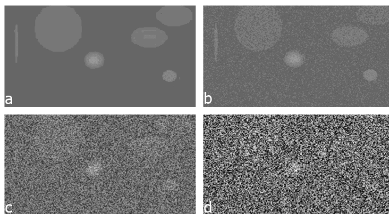

Figure 8. Effect of noise on detection probability of subtle image signals, a: original image, b, c, d: images with gaussian noise (ν_b=10, ν_c =20, ν_d=30)

In a noisy environment it becomes more difficult to detect subtle signals in an image. This is the case for noise in the image data itself (due to detector noise for example) but also for noise being added by the display system [9]. This effect can easily be demonstrated by looking to figure 8. This figure shows an original image (upper left) with several subtle signals such as ellipses, circles and lines. In the other three images an increasing amount of Gaussian noise has been added. It can be seen from these images that a higher amount of noise makes it much more difficult to detect these subtle signals. The effect is known as "masking effect", where the CSF decreases for medium frequencies if some higher frequencies as noise are present in the image. *Barten*'s model extended with external noise also confirms this (for more details we refer to chapter 2 of [2]). In presence of noise the human observer will be able to see less shades of gray than in a noise free environment. In high-end medical displays often a noise reduction technique is applied [10]. Such technique is able to reduce spatial noise in real-time. Tests with contrast phantoms [11] have shown that detection probability of low contrast signals improves when this noise reduction is applied.

Conclusion

Medical displays differ from consumer displays in several aspects. Not only medical displays have much higher brightness but they also have special calibration technology that guarantees image consistency. In addition high bit depth results into better compliance with medical calibration standards such as GSDF. To overcome decrease of luminance over time medical displays often contain luminance stabilization circuitry by means of a front sensor or backlight sensor. For demanding applications such as mammography technology to remove spatial noise has shown to improve detection probability of subtle image signals. Finally, medical displays are validated in depth and comply with stringent requirements such as the Food and Drugs Administration (FDA) regulations.

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