DICOM Calibration for Medical Displays

A Comparison of Two Methods

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Abstract

As medical institutions conquer the challenges of implementing PACS for enterprise-wide softcopy viewing, attention has increasingly turned to quality assurance of display performance, calibration and finding ways to easily attain visual consistency across numerous workstations with multiple flat panel monitors.

While most people are aware of the DICOM standard, few know exactly what it means to be DICOM calibrated and how display systems employ automatic calibration methods to assure conformance with the standardized display function specified in the DICOM documentation.

This paper looks at the basics of automated display calibration and compares two common calibration methods used by most monitor manufacturers today, reviewing their advantages and disadvantages.

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DICOM Calibrations For Medical Displays

Why Calibrate?

Because diagnostic confidence is critical for reliable image interpretations, users of medical displays need to know that the images they see are accurate depictions of the objects being studied. The view of the image must also be repeatable, not only for one specific display, but for every display in the healthcare enterprise.

Images of objects captured by a modality are stored on the PACS as a file with an array of picture elements with specific digital values based on relative signal levels that have been derived from the imaging equipment. These digital values are used to drive the display so that each picture element is reproduced at the right level of intensity to faithfully portray the image of the object as it was captured.

Calibration of the display system is important to ensure that each image is shown consistently every time it is viewed. LCD monitors need initial calibration to account for ambient conditions and map their light output range to the DICOM curve, then, due to the effects of aging, some form of automated or manual calibration is needed thereafter to ensure that they continue to conform to the standard.

DICOM Curve – A Display Standard to Match the Response of the Human Eye

The relationship between digital image drive values and displayed luminance on the display is based on models of the human vision system and measurements of how individual pixel values are mapped onto the display screen.

The way the human eye responds to contrasts in light levels is not linear. At low levels, we can notice small changes in luminance. At higher luminance, the change needs to be much greater before we perceive the difference from one level to the next. A curve can be plotted that shows measured luminance levels versus increments of perceived difference.

The DICOM curve was developed to represent how the human visual system is sensitive to changes in contrast. To ensure that all radiology displays are standardized to the way our eyes perceive luminance, the AAPM Task Group 18 developed the DICOM curve. On the DICOM curve an image is represented on a scale in incremental values from zero to 1023 with zero being the darkest and 1023 the lightest. Each grayscale increment corresponds to an increment in luminance, between .05 cd/m^2 (nits) and 4,000 cd/m^2(nits), that can just be noticed by the eye.

The result is a mapping of levels of luminance versus steps in visual perception. As a result, this DICOM curve describes the specific grayscale output of a display in a defined range of luminance values that are nearly linear in perception. This DICOM curve (fig. 1) is normally shown on a log scale of display luminance vs increments of gray level and has become an international standard. It is used to ensure an objective, quantitative approach for mapping digital image values to display devices.

By allowing us to standardize and map displays to the contrast sensitivity of the human eye, DICOM calibration assures that a given gray level will appear the same from one display to the next. It's the standard for viewing of grayscale medical images and is designed to reproduce approximately the same experience as we would get when viewing film.

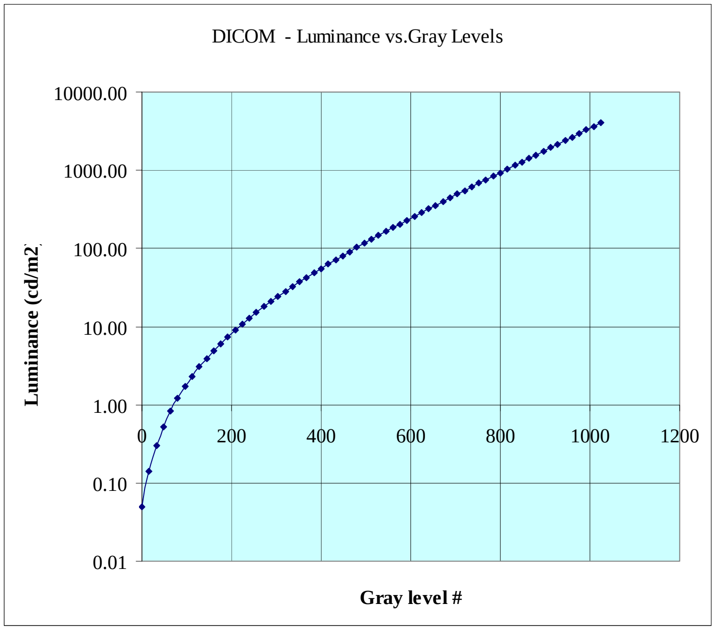

Fig. 1
The DICOM Curve shows that the human eye is more sensitive to contrast at low levels (vertical axis shown as the log scale of luminance).

A Primer on How AMLCDs Work

To understand how AMLCD displays are DICOM calibrated, we must first understand how they work.

When a drive level voltage is applied to an LCD display, it produces a corresponding output luminance. This output is a combination of light from the backlight going through a liquid crystal element and other optical elements to produce an image that can be viewed by the eye.

An active matrix LCD (AMLCD) monitor has a bright backlight, made up of multiple lamps, that acts like a film light box. Light from the backlight flows toward the viewer through an array of *pixels*, sets of tiny rectangular sub-pixel elements set into the glass layers of the display. Each sub-pixel is a light valve of liquid crystal material that opens and closes to let light from the backlight through, depending on the amount of voltage that's applied to it. On top of and below the pixels are layers of polarizers and other optical filters that improve image quality for the viewer. (See Fig. 3 for the basic structure of an AMLCD system)

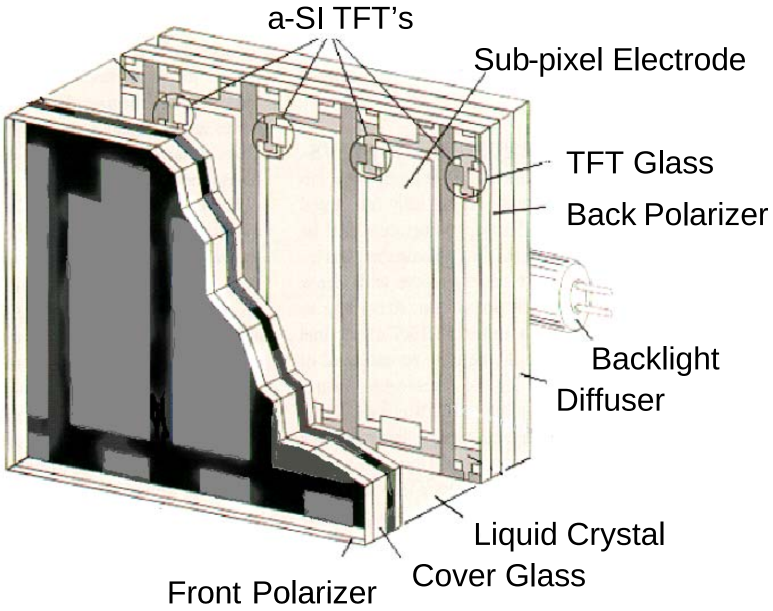

Fig. 3
Layers of an AMLCD Structure

In thinking about the DICOM curve, it should be noted that every AMLCD also has its own response curve. How much the liquid crystal material rotates to let light through from the backlight depends on how much voltage is applied to the pixel. Apply a lot of voltage and the molecules will rotate all the way, allowing a high degree of light to come through. Apply a small amount of voltage and the material doesn't rotate as much, allowing just a small amount of light to come through.

The amount of voltage needed to control pixels is not linear. In the mid-range, around 1.5 to 2.5 volts, you get almost the full transmission range, but the curve flattens out at the high and low parts of the range. This is what as known as the *response curve of the AMLCD*. (see Fig. 2) It should not be confused with the DICOM curve and it also must be taken into account when calibrating the display.

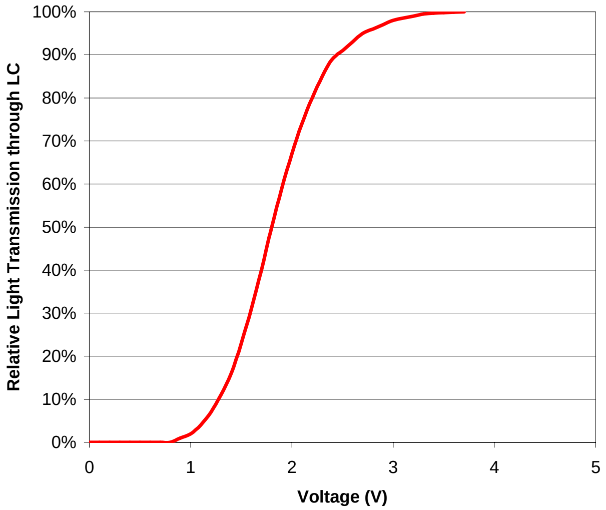

Fig. 2
Typical AMLCD Response Curve

Every liquid crystal element has a slightly different response curve that must be measured and mapped to the DICOM curve. (For example, to achieve a certain Digital Drive Level (DDL) state for pixel # 2,999,999, the voltage is *x*, and for pixel #3,000,000 the voltage is *y*.) That response map is put into a "Look-Up Table" (LUT) within the display. Essentially, the LUT becomes a memory map that says, for every pixel or for the average response over the whole panel, we know which voltage will give us a certain amount of output that can be mapped to the DICOM curve.

Studies have shown that liquid crystal material, glass and optical filters are stable over time and the characteristic response of the AMLCD does not change significantly during the normal use of a display.[1]

Planar does this LUT mapping for a number of different peak luminance levels right at the factory with a precision photometer and stores the data in memory on the display, providing for a display that has had its initial DICOM calibration before the user even takes it out of the box. In normal use, if the user needs to reset the upper limit for luminance due to changes in ambient room light the display can quickly re-calibrate itself with a DICOM curve relative to the chosen peak value. Other display makers may require the user to run an initial calibration program as part of the display's set-up routine or for every time the peak level is changed which may introduce errors or take time away from using the display for diagnostic applications.

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Two Methods to Maintain DICOM Calibration

When discussing DICOM calibration techniques, what most people are talking about is ***checking and maintaining*** calibration in a display that has already had its initial mapping to the DICOM curve. This checking and maintaining is what we will be referring to as we discuss calibration methods.

DICOM calibration involves two variables: 1) overall peak luminance and 2) gray level separation.

Overall peak luminance (white level) is provided by the display's backlight, which is set to run at a specific level of peak luminance. The initial maximum luminance of a backlight is usually greater than the peak luminance set point in order to allow for aging. Over time, the maximum output of the backlight will decline as the phosphors used in the lamps wear out. Setting the peak luminance to a level below the initial maximum provides some performance margin and allows the display to run at a continuous peak luminance using the calibration sensor feedback and the lamp control circuit. To maintain the DICOM curve as the display ages, the backlight must be adjusted by the inverter circuit to hold the peak luminance level constant.

Gray level separation involves accurate voltage control of the drive electronics of liquid crystal elements. This allows for each pixel valve to open or close as needed to provide the required level of light to pass through to produce the grayscale steps needed to achieve the DICOM curve.

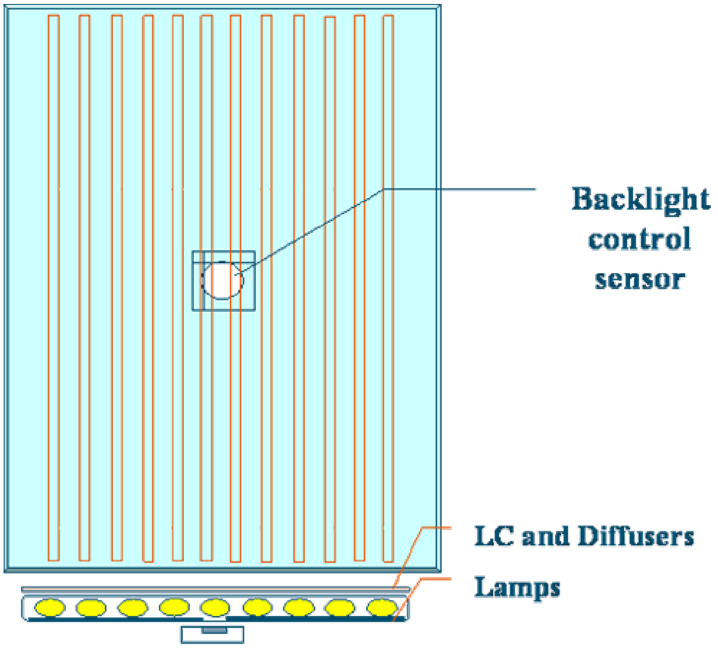
In the industry today, there are basically two methods of maintaining calibration for medical displays:

- Method A, which puts a backlight control sensor in the middle of the back of the display to measure peak luminance off the backlight.

- Method B, used by other display makers, which puts a tiny sensor on the front of the display, located right at the edge or corner of the active area.

Both methods A and B offer advantages and disadvantages.

Method A (Backlight Control)



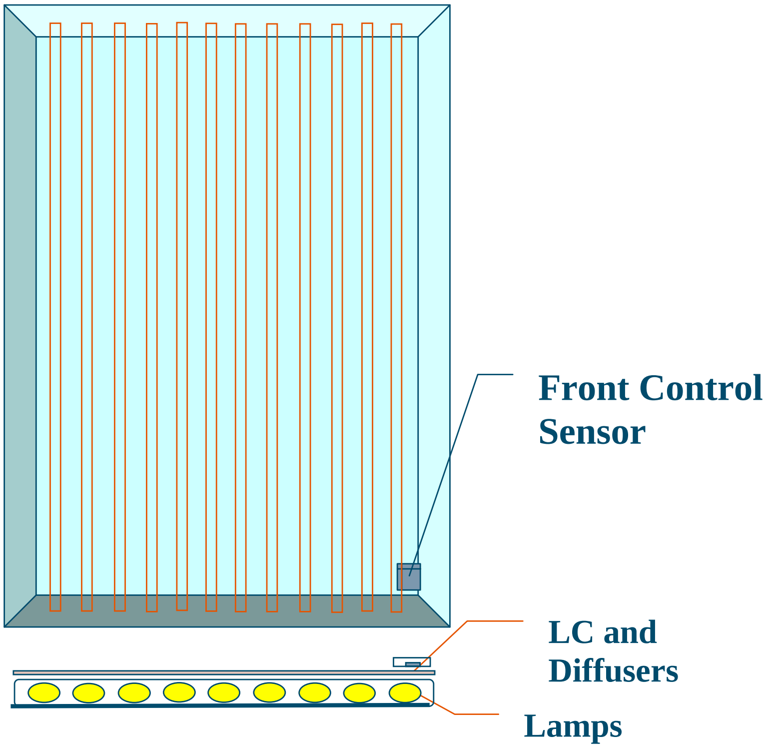
Method A, used by Planar and several other display makers, places a sensor at the back of the display that measures peak luminance from the display's backlight through the rear reflector without introducing non-uniformities at the front of the panel.

The sensor measures from the center of the display, where the viewer's eye looks most frequently, and it can average over multiple backlight lamps without any attenuation from the liquid crystals, polarizers and other layers that are in front of the lamps. This results in a direct measurement of the backlight performance, which is a critical factor in establishing the peak luminance of the display and all the subsequent grayscale levels of the display.

This method assumes that:

- Once the display's look-up table (LUT) is mapped to the DICOM curve at the factory, the liquid crystal matrix stays stable.
- The display's peak white level is held constant by the inverter control circuit for the lamps as their maximum light output degrades.
- Use of a photometer looking at the center area of the backlight is the ideal location for white level measurements.
- Use of the factory characterization of the liquid crystal matrix response map is the best way to control gray levels.

Method B (Corner Front View)



With Method B, a small sensor is incorporated on the front edge or front corner of the display, which means the sensor must look through the liquid crystal matrix and its filters. This method is based upon the idea that measuring from the front allows you to take into account any effects of the light passing through the liquid crystal.

This method assumes that:

- The display's peak white level is held constant by the lamp control circuit as its backlight maximum output degrades.
- Differences between the center of the display and the edge of the display for luminance measurement can be accurately accounted for over time
- The liquid crystal matrix is not stable due to fluctuations in temperature, and therefore it is necessary to monitor it from the front of the display.
- The effects of ambient light, sensor orientation to polarized light from the liquid crystal and temperature variations are insignificant when measuring grayscale levels.

Method A: Advantages and Disadvantages

While both methods of calibration offer advantages and disadvantages, Method A offers significant advantages, and its primary assumption – that the liquid crystal is stable -- has been proven by in-house research as well as in independent studies.[1]

Method A advantages include:

- **Larger Sensor**. Because it is placed at the back of the display, the Method A sensor is larger than the one used with Method B, which must squeeze a small sensor into the corner of the screen without obscuring the user's view. Larger sensors are generally more accurate than smaller ones because of a lower signal-to-noise ratio.
- **Area**. Method A's sensor measures the light of at least three lamps in the center of the display, a larger and more representative area, and it measures away from the end of the lamp, where lamp electrode decay over time cannot distort the calibration measurements.
- **Direct View of Backlight**. There is less attenuation of the backlight lamp signal in Method A because the sensor looks at the backlight. Therefore, users do not have to be concerned about whether the light valves (pixels) of the LCD are set correctly when measuring backlight peak luminance. (Method B looks "back" through the filters and liquid crystal, and attenuation from these elements may be an issue.)
- **User View**. Method A's sensor does not block any active area of the front of the display.
- **Ambient Light.** Stray ambient light does not enter the sensor and corrupt luminance measurements
- **Simpler System.** The direct, simple design of Method A introduces fewer potential errors from uncontrolled variables such as ambient light, edge effects and temperature.
- **Factory measurements for master LUT**. A precision instrument is used at the factory to measure every Digital Drive Level (DDL) on each display according to DICOM standards and establish the look-up table of settings for the LCD that are stored in the flat panel's internal memory for instant recall whenever needed.
- **Peak luminance selection**. The display can automatically apply the correct LUT depending on the peak luminance level chosen by the user.

No calibration method is perfect, and there are two disadvantages of Method A:

- **Not in Front**. Calibration is not done in front, where the viewer is.
- **No LC Detection**. Method A cannot remotely determine if the liquid crystal cell has failed. Because the sensor looks only at the display's backlight, the backlight can be working and, even if the liquid crystal isn't functioning, the sensor would not alert the administrator of a non-functioning display.

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Method B: Advantages and Disadvantages

The primary advantage of Method B, with its sensor in the front corner of the display, is that it looks at what the user looks at and can take into account any changes in the transmission of the glass and other optical elements on the front of the display. If those things change over time, this method can detect and compensate for it somehow.

Method B's advantages are:

- **Front Sensing.** With the sensor in the front, calibration takes into account the attenuated signal through the liquid crystal and filters.
- **LC Detection.** Because the sensor is in the front, it can remotely detect whether the liquid crystal is functioning.

Method B has a number of disadvantages:

- **Less Accurate.** The sensor this method uses needs to be small to fit into the display corner. Smaller sensors are less accurate due to higher signal-to-noise ratios.
- **One Lamp.** From where the sensor is mounted, it can only look at one lamp at the end of the stack where non-uniform aging can occur.
- **Edge Sampling.** The front-mounted sensor samples near the edge of the liquid crystal cell where the cell is more non-uniform and can change over time with mechanical pressure from the frame or handling.
- **Signal-to-Noise.** The sensor looks at highly attenuated backlight level signal through the glass and operates in a range where signal-to-noise could be an issue (especially at low luminance levels).
- **Complicated Design.** Method B requires a more complicated control circuit and design.
- **Two-Step Process.** Method B is a two-step process of backlight adjustment that may have to be repeated due to interdependent variables (white level, then liquid crystal adjustment).
- **Center-to-Edge.** It assumes center-to-edge relationships of the display are consistent over time, which is not possible because the edge of the display is subject to different conditions than the center of the display over time. It is hard to correlate with the rest of the cell over time without periodic external calibration and re-assignment of correction factors.
- **Atypical Diagnostics.** Method B uses a part of the screen for calibration that is not normally used for diagnostics.
- **Recalibrate Externally.** With Method B you may have to recalibrate at unpredictable intervals with a reliable external sensor to bring the onboard sensor system back into proper range

Conclusion

Both calibration methods have advantages and disadvantages. If you assume that the liquid crystal structure in the AMLCD stays stable, then Method A with its backlight control sensor, which is used for automatic calibration on Planar medical displays, is clearly superior to Method B's corner front sensor.

Our belief in the stability of the liquid crystal has been supported by independent studies presented at SCAR and other professional venues. A recent study at the University of Texas using Planar's Dome C3™ displays with CXtra Rightlight™ found that the "vendor's claim of 'always calibrated' is justified."[1]

With independent verification of Method A's key assumption, we believe the advantages gained by calibrating with Method A's backlight sensor far outweigh anything that could be gained with Method B.

References:

1. "Validation of a Self-Calibrating Active-Matrix Liquid Crystal Display System" presented at SCAR 2003 by Stephen K. Thompson, M.S., Chuck Willis, Ph.D., Raimund Polman, and Kenneth L. Homann, Department of Diagnostic Imaging Physics, University of Texas.

2. "Digital Imaging and Communications in Medicine (DICOM) Part 14: Grayscale Standard Display Function" Published by: National Electrical Manufacturers Association.