Monitor **QA**

Monitor QA Management "i model"

TOTOKU

White Paper

Flat Display Systems for Medical Imaging

Monitor QA Management "i model"

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2007/06/13/ veR10.5 M.H.

1.   Preface

Together with the growing prevalence of PACS and the increasing awareness of medical diagnostic display quality management, guidelines and international standards are being developed around the world. Simultaneously, the healthcare industry has become more aware of the necessity to implement a simple and quantitative quality management on a daily basis in order to keep up with the increasing number of medical displays installed on site.

In response to this demand, TOTOKU has brought the "i model" into the market. The i model is equipped with a luminance sensor situated in the front panel to easily manage the quality of luminance and gamma which are the factors that determine image quality in medical image displays. The luminance sensor also simultaneously provides high accuracy image stabilization.

Also, when used in combination with TOTOKU's performance monitoring software "PM Medivisor", it is possible to automatically perform quality management of TOTOKU displays on PACS. As this software significantly simplifies the data management, PACS administrators can reduce the time and cost required to perform display quality management.

In this paper, we discuss what quality means for diagnostic displays, what are factors that affect quality and how TOTOKU addresses the quality control with the "i model" featuring the new luminance stabilization system.

2.   Changes in Image Quality

2-1   Relationship between luminance and gamma

As it is noted in the previous section, "luminance" and "gamma" are important factors that determine quality in medical imaging. In this section we will clarify the reasons.

Gamma essentially refers to the output luminance characteristics versus the input values of a display. For medical displays, these characteristics are defined as GSDF (Grayscale Standard Display Function) in DICOM Ver.3 Part 14. Originally, gamma refers to the inherent characteristics of a display device, and GSDF refers because it refers to the characteristics of the entire system. Although their definitions are not exactly the same, we shall use the term gamma and GSDF identically in this paper as a matter of convenience. DICOM (Digital Imaging and Communications in Medicine) is the standard specifications that apply to digital imaging and communications in the medical industry. 'Part 14', a portion of this standard, covers specifications related to medical displays and printers equally reproduce the appearance of images on all display devices.
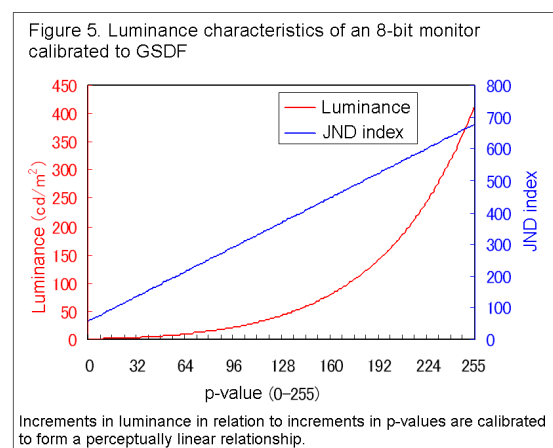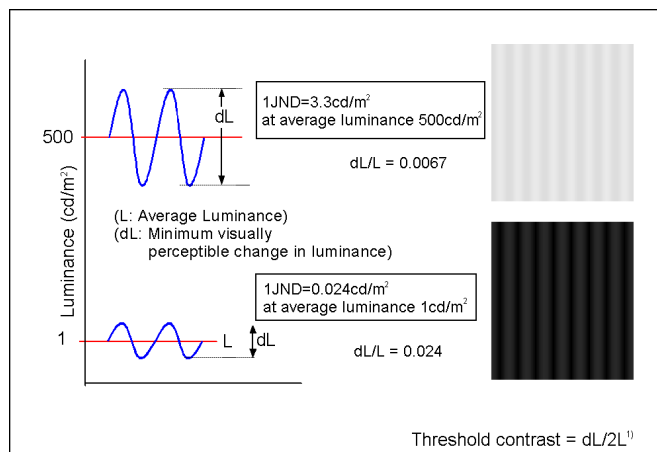

Figure 1. The visual model and luminance characteristics

GSDF as defined here is based on the "Barten Model", a model of the visual characteristics of human eyes, which enables visually linear grayscales at the entire range of low to high luminance. The concept of JND (Just Noticeable Difference) is useful to understand the mechanism.

JND is defined as the minimum amount of change in luminance necessary for human to perceive. As shown in Figure 1, the required change in luminance for human perception is less in lower levels of luminance, but the change is greater in higher levels of luminance. Human eyes are more sensitive to brightness changes in lower luminance, and are less sensitive in higher luminance. GSDF is defined so that the number of JND at each step of the input signal is equal, which enables a visually linear grayscale to be obtained.

One of the key things is that GSDF is uniquely determined based upon the minimum and maximum luminance output from the display unit. In other words, GSDF will be different for a display with a maximum luminance of $300cd/m^2$ from the one with a maximum luminance of $400cd/m^2$. Luminance and GSDF are closely interrelated – Let's say the gamma that conforms to GSDF at given point changes, it will no longer conform to the GSDF   to the GSDF after the changes. We will see in detail what problems arise when luminance changes.

Let us consider an example where a display is calibrated with DICOM GSDF at the maximum luminance of $400cd/m^2$, and then the maximum luminance later falls by 20% due to backlight degradation. The maximum luminance is now $320cd/m^2$. The gamma of the display is still set to GSDF with maximum luminance of $400cd/m^2$, but a discrepancy now exists between the current gamma setting and the required GSDF setting for the current maximum luminance of $320cd/m^2$. This is visually represented in Figure 2.

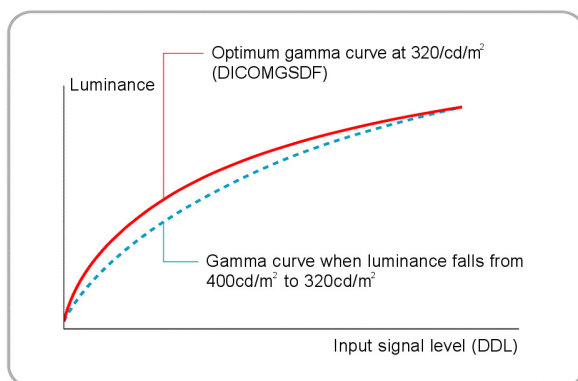Figure 2. Comparison of gamma curve at 20% reduced luminance

This figure shows that when luminance falls from $400cd/m^2$ to $320cd/m^2$, a discrepancy appears between the previously set gamma and the target gamma of $320cd/m^2$. The visually perceptible linear gradation is no longer ensured, which may interfere with appropriate image diagnosis.

Not limited to the changes in grayscale as noted above, a change in luminance may also negatively influence diagnosis. PACS workstations usually have 2 (or more) medical imaging displays connected. As displays are placed side by side, a luminance variation between these displays may trigger visual or psychological stress for physicians.

From the above, we conclude that (1) display gamma must be correctly calibrated based on the DICOM GSDF in accordance with the luminance specified, and that (2) the luminance must be maintained at a constant level.

2-2   Causes of luminance changes

We discussed how luminance changes affect gamma and described why luminance must be stabilized. Now let us consider what causes a variance in luminance. The possible causes are mainly described as follows:

- A change in brightness of the backlight light source components (fluorescent lamps, etc.)
- A change in the reflectivity over time and transmittance of optical components in the LCD unit.

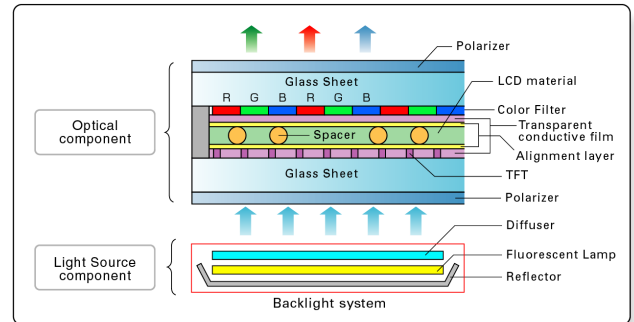We will look into each factor for variation in the following section.

Figure 3 LCD panel cross section

2-2-1   Light source

Fluorescent lamps are commonly used as backlights due to their high luminescence efficiency. Cold cathodes are situated on each end of a fluorescent lamp, a rare gas and a small amount of mercury are filled within the glass tube, and the inner walls are coated with luminescent material. By applying high voltage to each end of the glass tube, electrons get emitted at high speed from the electrodes. These electrons collide with the mercury atoms, which emit ultraviolet rays. The phosphor layer on the inside wall of the glass tube converts these ultraviolet rays into visible light.

Luminance output varies greatly depending on the temperature of the glass tube walls and the lamp current. After extended use, the mercury degrades and the phosphor deteriorates in quality. The results in the decreased luminance.
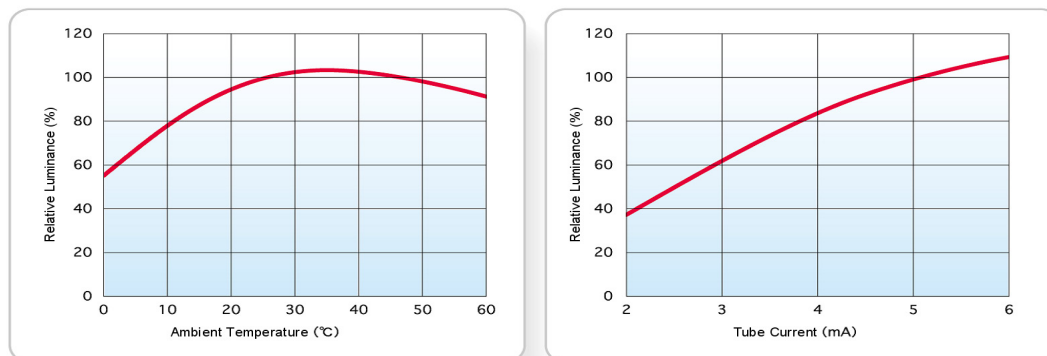
Figure 4. Luminance change according to ambient temperature and lamp current

2-2-2   Optical components in the backlight unit

There are two types of backlight. One is the direct backlight type, in which the light source is located directly behind the LCD panel. The other is the edge light type, in which light sources are located along the top and bottom or the left and right edges of the panel. For either of these types, various plastic optical materials are used, such as diffusers to reduce unevenness in the light-emitting surface, reflective sheets to increase the lighting efficiency, and brightness enhancement films that efficiently guide light to the front of the screen. Also, plastic light guide plates are used in the edge light type to evenly spread light from the light sources at the edge to all areas behind the liquid crystal panel.

Fluorescent lamps are designed in such a way to minimize leakage of ultraviolet rays, but a small amount may leak through these barriers and expose these plastic materials located within the close range (Figure 3). After certain time has passed, these optical materials degrade and luminance decreases.

3. Solution Presented by "i model"

This section describes how the "i model" resolves the problems caused by the factors affecting luminance to enable high precision in luminance stabilization, and furthermore explains how luminance and gamma accuracy are managed.

A commonly used luminance stabilization mechanism consists of a light control circuit, a luminance sensor, and a feedback system. It becomes apparent that the properties of the installed sensor, its location, and the accuracy of the light control circuit all can affect the degree of stabilization.

In developing the "i model", after carefully examining various methods, TOTOKU introduced the built-in "front sensor " where the sensor is located in front of the LCD panel. Even higher-level accuracy in luminance stabilization is achieved by combining the accumulated know-how on the luminance stabilization system with a built-in front sensor. With the "i model", luminance is monitored in real-time and actual luminance values can be shown on the OSD (On Screen Display). Also, gamma accuracy is easily managed by running the AAPM DICOM GSDF conformance test. When used together with the optional software "PM Medivisor", quantitative quality management of luminance and gamma can be automatically performed.

3-1 Built-in front sensor

What are the benefits of the built-in front sensor in the "i model"? In the previous section, we described the luminance stabilization system as a feedback system comprised of a luminance detector sensor and luminance control circuit. There are two types of luminance stabilization systems; one is the system using a front sensor technology, and the other is the one using a backlight sensor technology.

The backlight sensor technology is an extremely effective way to stabilize the light source. For instance, as a display is turned on, the temperature of the backlight itself and the ambient temperature increases, which both affect the backlight luminance. Using this backlight sensor technology dramatically reduces the time for luminance to stabilize after power-on. Also, this method can sufficiently manage backlight degradation that occurs after long periods of use. However, changes in the "amount of light that reaches the operator" due to luminance variations within the panel, as described in Chapter 2, are not included in the feedback loop. Therefore, this method cannot compensate for such variations.

On the other hand, the front sensor technology can constitute a feedback loop including the optical components and has better stability in luminance than the backlight sensor technology in luminance stabilization. Also, by situating the sensor on the panel, gamma quality control is feasible since it can measure luminance of any gradation sequence output by the panel.
The front sensor technology can be further roughly classified into fixed and retractable types. The table below describes this in detail. After examining the benefits of each technology, TOTOKU decided to introduce the fixed type. Benefits of the fixed type include being free of mechanical noise and resistant to breakdowns, whereas these problems are potentially inherent in the retractable type.

The "i model's built-in front sensor" is designed to be extremely small in order to not interfere with diagnosis. The sensor is in an extremely close contact with the panel surface, and is shielded optically so as not to get affected by the ambient light. This sensor is always working when the display is in use. Therefore, it can monitor the luminance in real time. In other words, it can stabilize the luminance.

And diagnosis can be continued without interruption even during gamma evaluation.

Because the measurement area where several gray levels are displayed is not on the actual working area but just beneath the front sensor.

Table 1. Sensor Types Comparison

Type of Luminance Sensor	Fixed Built-In Front Sensor (Used in TOTOKU's "i model")	Retractable Built-In Front Sensor	Backlight Sensor
Advantages	1. Fixed design has no mechanical points of failure. 2. Sensor does not emit unpleasant noise that might interfere with diagnosis. 3. The display's luminance can be monitored in real time. 4. The display's gray-levels can be monitored.	1. Sensor is stored in the display bezel when not in use to enable full screen visibility. 2. Gray-levels luminance can be measured.	1. Full screen is visible because the sensor is housed behind the backlight. Fixed design. No mechanical points of failure.
Limitations	1. A portion of the screen edges is obscured by the sensor. ("i model" sensor size: 5mm square)	1. Design is complex due to the mechanical parts. 2. Mechanical components used by the sensor may create noise when under operation. 3. The display's screen luminance cannot be monitored in real-time.	1. Luminance changes in optical components are out of feedback. 2. Gray-levels cannot be measured.

3-2   Luminance stabilization system

Let us now explain the structure of the built-in front sensor technology of the "i model".

Figure 5 shows the diagram of the luminance stabilization system with built-in front sensor.
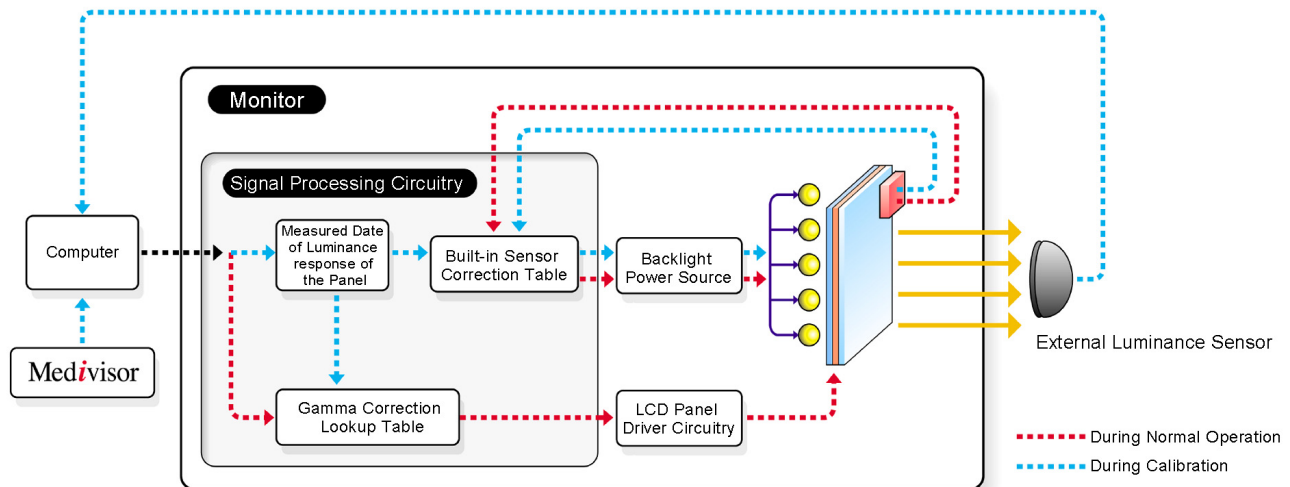

Figure 5. Diagram of i model's built-in front sensor

In order to achieve high level of luminance stabilization, the system is highly optimized in different levels such as components, structure, circuit, and firmware, etc.

Compensation for the built-in front sensor is a part of the optimization. It is not unusual that LCD panels show luminance unevenness. Since the center of the screen is mainly used for diagnosis, center luminance must be stabilized. Although the built-in front sensor of the "i model" is situated in a corner of the screen, it is able to manage center luminance as if it was situated at the center. This is possible because the built-in front sensor is supported by a correction table containing data of center luminance and corner luminance.

The correction table is created upon regular calibration with an external luminance sensor attached to the center of the screen.

The data obtained will be used as a reference of the luminance control circuit, which is updated with every external calibration.

The luminance stabilization is operated whenever the display is on. Luminance variation from the target value (maximum luminance) is continuously corrected several tens of times per second at the beginning and several times per second after luminance stabilizes. This is because the rate of variation is higher for a certain time after start-up. Figure 6 shows the " Luminance behavior with and without control ". With the "i model", the time that the luminance reaches its target is significantly reduced to less than 1 minute, whereas it takes approximately 60 minutes without luminance control. As we can see on the figure, luminance variations are also controlled during operation.
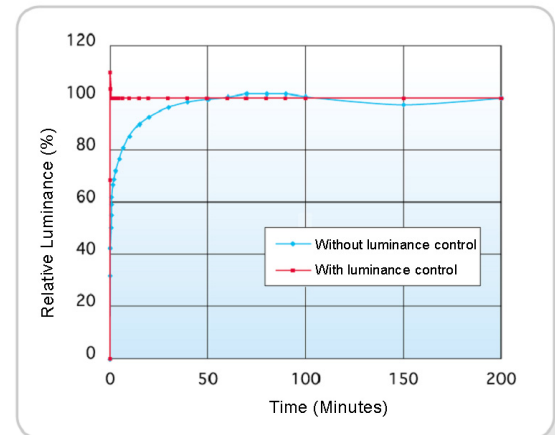

Figure 6. Luminance behavior with and without control

The current luminance value can be displayed on the OSD (On Screen Display) so that users can easily check luminance conditions.

Also, when used with performance monitoring software "PM Medivisor", it keeps track of the luminance for all displays that are connected to the network and provides information to administrators, avoiding the trouble of having to access each display's OSD. Moreover, if the luminance cannot be maintained to the target value due to failure or end of life of the backlight, an alarm is displayed on "PM Medivisor", to reduce the risk of false diagnosis under unsuitable luminance conditions.

3-3 Evaluation of DICOM-GSDF conformance

With the "i model", it is possible to evaluate the gamma characteristics easily. As described earlier, in medical displays gamma characteristics must conform to DICOM GSDF. There are several methods to achieve it, but the evaluation method as defined in the AAPM TG18 guidelines related to medical displays can be considered to be the most well known. TOTOKU's "i model" employs this evaluation method and makes it possible for users to see clearly whether or not the display is in compliance with GSDF.

In the AAPM TG18 luminance response characteristics evaluation (i.e. gamma evaluation), a total of 18 luminance value measurements are taken, including the minimum and maximum luminance and 16 intermediate levels of luminance between these. The front sensor is indispensable in performing these intermediate luminance measurements. The luminance measurement can be performed only at the area where the front sensor is located, thus there is no disturbance with diagnosis. Evaluation results can be viewed and managed by "PM Medivisor", and if, for some reason, the evaluation results are not in compliance with DICOM GSDF, an alert will be sent to the administrator notifying that calibration is necessary.

Well then, how is this AAPM TG18 luminance response characteristics evaluation performed? We will explain as follows.

1） 18 luminance measurements are obtained from the minimum to the maximum. For a standard PC system, it measures in 15 increments from 0 to 255 for the video signal's digital driving level (DDL). Let us define each of the measured luminances as $L'_0, L'_1, L'_2 \ldots L'_{17}$.

2） The numbers of JND between the neighboring luminance measurements L'_I and L'_{I-1} is calculated. $(J_{I-1}-J_I)$

3） The luminance variation between neighboring luminance measurements, or contrast, is calculated. $(L'_I+L'_{I-1})/2(L'_I-L'_{I-1})$

4） The luminance response value δ, or contrast for a JND in each measurement range, is calculated. $\delta_i = 2(L'_l - L'_{l-1})/(L'_l + L'_{l-1})(J_{l-1} - J_l)$

5） The above steps 1) - 4) are performed for the target DICOM GSDF, and the target luminance response value δ_i^d is calculated.

6） The difference of the luminance response between DICOM GSDF and measured data is calculated. $\kappa_\delta = Max(|\delta_i - \delta_i^d|)$

7） For diagnosis applications, this value is considered to be in compliance with DICOM GSDF if it is less than 10%; if it is more than 10%, it is considered as out of compliance.

The luminance response value δ calculated above represents what kind of curve is drawn for the gamma.

The final value κδ shows how close the measured data gets to the DICOM GSDF.

We can see that the DICOM GSDF conformance test is complex, but users can automatically perform this test by using the "i model" with "PM Medivisor". It is also possible to view the history of previous test results and to configure scheduled tests.

Even when the test is running, user can continue diagnosis comfortably because the test is done in a very short time and there is no impact on the viewer and other application since the load on workstation by the test is very light.
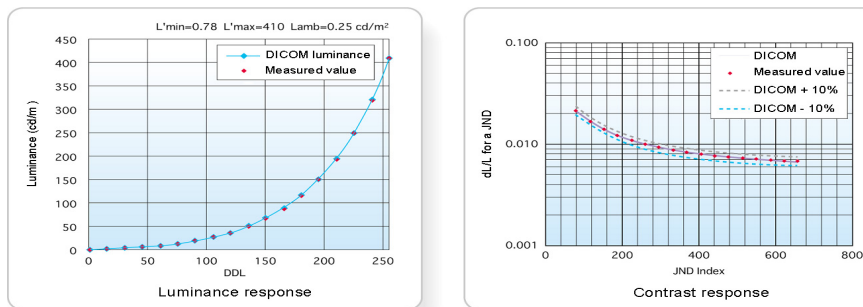

Figure 7. DICOM GSDF conformance test example (color monitor example)

4.   Summary

This paper has explained the changes in luminance and gamma that occur in LCD panels in detail. Additionally, we also described how the new luminance stabilization system introduced in TOTOKU's "i model" deals with these changes. We have seen that stabilization of luminance and gamma is extremely important in medical displays, and TOTOKU's new system employs various innovative techniques to achieve stability at a high level.

The quality management system provided by TOTOKU's "i model" offers easy and quantitative quality control for everyone. The workload on the system administrators can be greatly reduced even in a large PACS installation.

We would like to conclude by summarizing the benefits of the "i model's" as follows:

(1) Because the luminance control loop includes the entire optical system, the higher levels of stabilization can be obtained, compared to the widely used backlight sensor system.

(2) The built-in front sensor is calibrated using a standard luminance sensor at factory, and the correction table containing the compensation data is stored in each display. Subsequently, the compensation data for the front sensor is automatically updated every time the display is calibrated with an external luminance sensor.

(3) DICOM conformance test result, luminance data and other information e.g. calibration history can be managed collectively and automatically with TOTOKU's performance monitoring software "PM Medivisor".

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