DENTAL MONITOR CALIBRATION

A REPORT ON DENTAL IMAGE PRESENTATION

By Tom Schulte

Dental radiographs and oral photographs are often both viewed on the same dental workstation monitor. The two types of images have vastly different technical characteristics and viewing intents, however.

This report examines the different monitor presentation requirements for the two types of dental images. We examine some of the technical characteristics of human vision and how that drives the requirements for scanned image presentation. The report gives an overview of pertinent radiology imaging standards. We also examine the progression of color photography and computer image color space conventions to the current state.

We then present the CalMAN Dental solution for dental monitor calibration. We present a quick, convenient method of creating multiple monitor calibration profiles to individually calibrate a monitor for accurate presentation of either grayscale radiographs or color photographs, as selected by the user to match the type of image currently being viewed.

Dental Images

In dental facilities, computer monitors are often used to view both grayscale radiographs and color photographs.

- Dental radiographs are scanner-sourced images that use non-visible X-ray energy to form an interior image of oral body regions.

- Dental photographs are camera-sourced images that use visible light to form a surface image of oral body regions.

Due to differing characteristics between scanner-sourced radiographs and camera-sourced photographs, there are different performance requirements for displays used to accurately present these two types of images for viewing. Each type of image requires different monitor performance characteristics for optimum image presentation. Usually, however, a monitor's native or aged performance doesn't meet the specifications for accurate presentation of either type of image.

Grayscale Radiographs

X-ray scanning systems are designed to produce image brightness levels that are seen to have a linear relationship to the internal densities of the tissue, bone, and teeth being scanned. However, these systems produce digital image data that has an approximately logarithmic relationship to the internal densities of the scanned body parts.

> *The contrast of darker areas of scanned images presented on electronic monitors must be enhanced to achieve perceptual linearity.*

If the logarithmic image data produced by these scanning systems were to be displayed on a computer monitor with a logarithmic luminance response*, the monitor would then produce image brightness levels that would be seen to have an approximately linear relationship to the scanned object densities.

*A monitor's luminance response is the relationship between its digital drive levels (e.g. 0-255) and the resulting screen luminance.

There are two important factors to consider, however, when displaying radiographs on computer monitors.

1. Computer monitors do not natively exhibit a logarithmic luminance response.

Monitors usually have a luminance response that is approximately a power function, with an exponent (gamma) of 2.2, which is the industry sRGB standard for presenting web and other photographic images.

2. The Human Visual System (HVS) exhibits an approximate logarithmic luminance response over much of its range, but not at lower brightness levels.

The contrast sensitivity of the HVS depends on factors that include the absolute luminance level, the luminance difference, the ambient lighting environment, among others. Including all factors, human contrast sensitivity is approximately logarithmic above an image luminance of about 20 cd/m^2 (Figure 1).
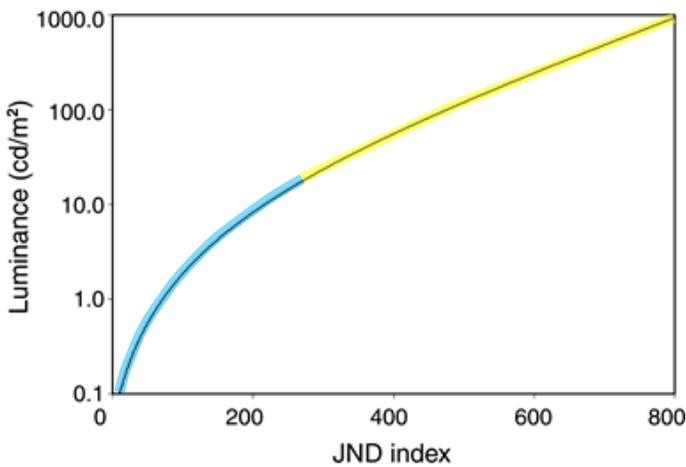

Figure 1: Above approximately 20 cd/m² (in yellow), human contrast sensitivity is almost purely logarithmic (linear plot with the log luminance scale). Below 20 cd/m² (in blue), contrast sensitivity decreases.

At luminance levels below about 20 cd/m^2, however, the contrast sensitivity of the HVS diverges from its near-logarithmic response, with decreasing contrast sensitivity at lower luminance levels (Figure 1).

Thus, the contrast of darker areas of scanned images presented on electronic monitors must be enhanced to achieve perceptual linearity between scanned object densities and image brightness. (Dental films on traditional light boxes produce luminance levels that are mostly above 20 cd/m^2 and don't require this contrast enhancement.)

Therefore, for accurate presentation of scanned radiographs, a monitor's luminance response should be approximately logarithmic at higher luminance levels, with additional compensation for reduced HVS contrast sensitivity at lower luminance levels.

> *Inconsistent image presentation from one monitor to another causes inconsistent patient diagnoses and healthcare decisions.*

Radiology Imaging Standards

Since a given radiograph may be viewed at different locations within and across dental facilities, on monitors with different native characteristics, images produced by the same image file can present completely different visual appearance, information, and characteristics on those different monitors. If uncorrected, this inconsistent image presentation from one monitor to another causes inconsistent patient diagnoses and healthcare decisions.

Accurate and consistent presentation of images across different monitors is the goal of radiology imaging standards.

DICOM Standard

The American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) formed a committee in 1984 that produced the Digital Imaging and Communications in Medicine (DICOM) standard.[1] Part 14 of the DICOM standard specifies a luminance response model for scanned images known as the Grayscale Standard Display Function (GSDF).

The intent was to cause radiographs to be displayed on any GSDF-conforming monitor with consistent contrast across the brightness range. The DICOM GSDF is the standard luminance response model for viewing scanned medical images. It is designed to produce approximately the same viewing experience on digital monitors that we would experience when viewing radiology film.

The DICOM GSDF matches a monitor's luminance response to the nonlinear perceptual characteristics

of our vision, based on Barten's model of human contrast sensitivity[2,3]. At luminance levels below about 20 cd/m^2, the DICOM GSDF departs from a near-logarithmic model to match the nonlinear perceptual characteristics of the human visual system (Figure 2).
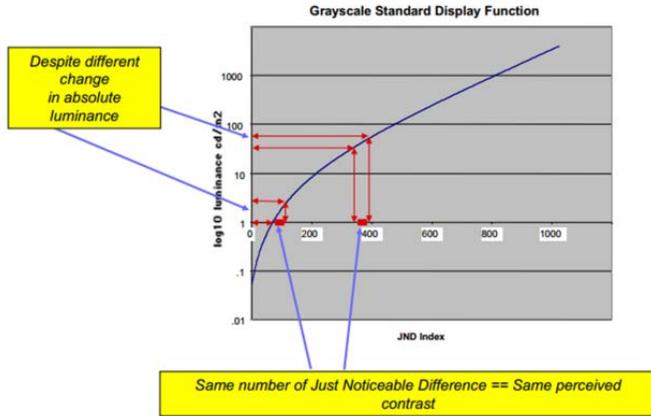

Figure 2: The DICOM GSDF function, showing the luminance on a log scale as a function of the JND index, as obtained from Barten's model of human contrast sensitivity. Note that the same perceived contrast (JND range) can result from different absolute luminance differences.

The GSDF maps scanned image values to digital driving levels (signal bit levels), such that equal changes in image values produce equal changes in perceived brightness. The brightness changes are measured in terms of Just-Noticeable Differences (JNDs) of brightness. Each equal step in image values should produce a perceptually equal brightness change, across the monitor's entire luminance range.

The DICOM Grayscale Standard Display Function (GSDF) insures that each image level captured by an X-ray scanner is uniquely perceivable on a GSDF-conforming monitor.

> *Each equal step in image values should produce a perceptually equal brightness change.*
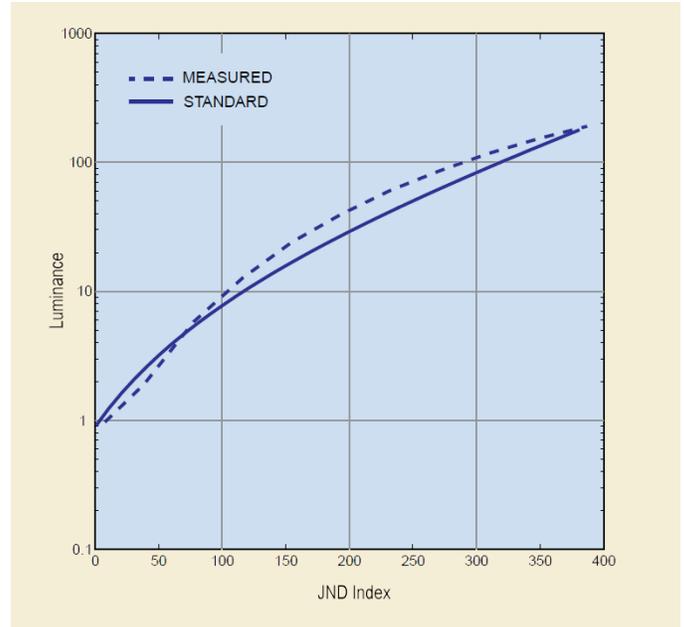

Figure 3: Measured luminance response of typical uncalibrated monitor, compared to response of DICOM GSDF standard.

The DICOM standard defines the GSDF luminance response model for radiology monitors, while the American Association of Physicists in Medicine (AAPM) and the American College of Radiologists (ACR) specify monitor test procedures and acceptance criteria.

AAPM Guidelines

Task Group No. 18 of the AAPM published their On-Line Report No. 03 - Assessment of Display Performance for Medical Imaging Systems[4]. The intent of the report was "To provide standard guidelines to practicing medical physicists, engineers, researchers, and radiologists for the performance evaluation of electronic displays intended for medical use."

ACR Standards

The American College of Radiology (ACR), in collaboration with the American Association of Physicists in Medicine (AAPM) and the Society for Imaging Informatics in Medicine (SIIM), has published technical standards[5] that, in part, cover radiology diagnostic and clinical displays.

Ambient Room Lighting

If the screen luminance due to reflected ambient light is equal to or greater than the monitor's minimum image luminance (black level), the ambient luminance reduces the ability to perceive contrast between the darker gray levels in a radiograph. The ambient luminance effectively compresses or 'washes out' the darker gray levels, reducing the image contrast (Figure 4).
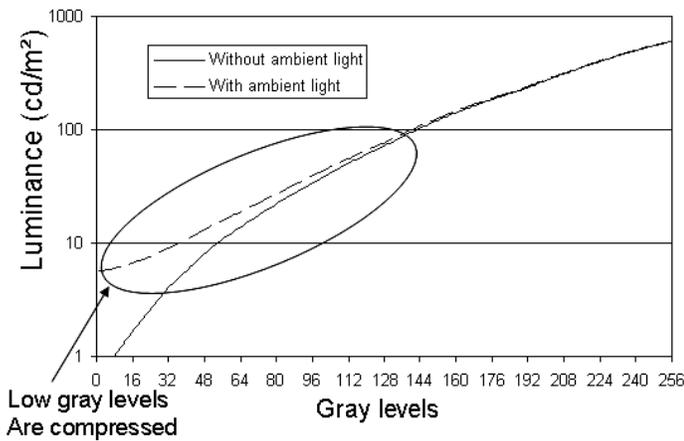

Figure 4: Ambient light, when added to a monitor's native (uncalibrated) luminance response, causes the darkest image levels to be compressed, blending them together.

Most dental radiographs are viewed in a normal office environment, with at least a moderate level of ambient lighting. Without some image compensation for the ambient luminance, all contrast distinction will be lost in the darker image areas. The contrast difference between the darker gray levels of a radiograph will not be visible if the gray levels are not brighter than the reflected ambient luminance.

Ambient Luminance Compensation

To insure accurate visual perception of all radiograph gray levels, a monitor's darkest gray luminance levels need to be higher than the monitor's ambient luminance level.

This means that a monitor's native "black level" normally needs to be increased, to enable accurate perception of the darkest gray elements. Because digital monitors don't usually have a black level control, the image black level needs to be increased before the graphics adapter applies the image values to the monitor as digital drive levels. This is done with a lookup table (LUT) of luminance calibration values applied to the workstation graphics adapter.

Note that higher levels of ambient light can be tolerated when viewing medical films on light boxes, because, as noted above, the lowest luminance levels produced by trans-illuminated films are mostly above 20 cd/m^2; much higher than the lowest luminance levels produced by the monitors used to display digital radiographs.

Color Photography Standards

Before 1999, cameras, scanners, printers, and monitors, both individual models and collectively, all had different color spaces (methods of specifying or creating color). There was not a standard color space designated for creating, printing, and viewing color photography and web images.

Some color devices were and are based on the "additive" color system using RGB, while others are based on the "subtractive" color system using CMYK. Some devices were capable of working with a wide range of colors, known as the device gamut, while others worked with a narrower color gamut and not all devices used the same color illuminant.

These different color spaces were all incompatible with each other. A color image created in one color space by a camera or scanner looked different when reproduced by a printer that had a different color space and different yet on a monitor with another color space.

Color Management

In 1993, eight industry vendors established the International Color Consortium (ICC) to create a cross-platform color management system. The outcome of this cooperation was the ICC profile specification. ICC device profiles can be used to translate color data created on one device into another device's native color space.

In this color management system, each input and output device has an ICC profile that describes its native color space and each image file includes embedded profile data that describes its originating color space. An ICC-compliant image editing or image viewing application is able to combine an

image's embedded profile data with the profile data from a target output device (monitor or printer) and use that combined data to modify the color space of the image so that the image data produces the desired look on the target output device.

To work seamlessly, the ICC color management system requires that all devices have an accurate profile installed and that all images have accurate profile data embedded in the image file.

Color Space Standard

Instead of attempting to manage the different color spaces of color input devices, color images, and color output devices, Hewlett-Packard Co. and Microsoft decided to create a single, standard color space that could be used by all color devices and images.

They created the sRGB color space, which was standardized in 1999 by the International Electrotechnical Commission (IEC) as IEC 61966-2-1. The World Wide Web Consortium (W3C) adopted sRGB as the standard color space for all images on the internet. Microsoft made sRGB the default Windows color space, beginning with Windows 98, for all color images that do not have an embedded ICC profile.

This standard sRGB color space enables a simplified method of accurately handling color within a computer operating system and on the internet. sRGB is the world's default color space for digital images, cameras, scanners, printers, photo labs, monitors, and the internet. Use sRGB and you'll get great, saturated, and accurate color everywhere, all the time.

> *This standard sRGB color space enables a simplified method of accurately handling color.*

No photographer needs to do color management manually any more. Color management, defaulted to sRGB, is now built into everything by designers who know what they're doing. Any attempt to outsmart them usually delivers worse results than just using the sRGB color space for all input and output devices.

All you need to worry about is having your monitor calibrated to accurately display sRGB images. CRT monitors actually came close to matching the sRGB standard, if their factory settings were maintained. Most LCD/LED monitors with factory settings don't come close to matching the standard, however.

Alternate Color Spaces

Some may be tempted to create photos in other color spaces, perhaps Adobe RGB for example, which can theoretically represent a wider range (gamut) of colors than sRGB. However, Adobe RGB squeezes colors into a smaller range (makes them duller) before recording them to an image file. Special software is then needed to expand the colors back to where they should be when opening the file. You cannot use Adobe RGB on the internet or for email or conventional photo lab printing. If you do, the colors will be lower saturation, dull looking. Using the sRGB color space throughout a photography process gives more consistent results than alternate wide color gamuts and gives the same, or brighter, colors.

> *All you need to worry about is having your monitor calibrated to accurately display sRGB images.*

Competing Presentation Requirements

Dental facilities often use the same computer monitors to view both grayscale dental radiographs and oral color photographs. These two types of images require totally different monitor performance characteristics for optimum image presentation. Usually, however, a monitor's native or aged performance doesn't meet the specifications for accurate presentation of either type of image.

So, how can a dental workstation monitor accurately present both grayscale radiographs and color photographs or web images?

Read on…

CalMAN Dental

CalMAN Dental monitor calibration software automatically calibrates a dental monitor for optimum presentation of both grayscale radiographs and color photographs. Two calibration profiles are created and saved to the workstation. A "Radiology (X-ray)" profile is created to correct the monitor for accurate presentation of dental radiography images and a "Video (sRGB)" profile is created to correct the monitor for accurate presentation of oral photography images, web images, or videos.

A workstation user can select the monitor profile to match whether grayscale radiographs or color photographs are being viewed. The desired monitor profile can be selected by opening the calibration client icon that resides in the computer's system tray (Figure 5).
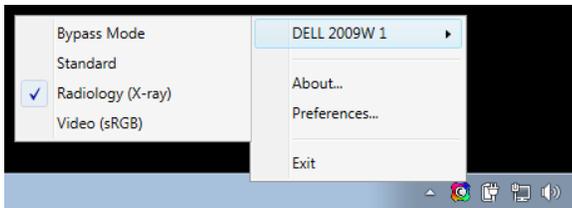

Figure 5: The CalMAN Client icon that resides in the computer's system tray provides selections for the desired monitor profile.

Guided Calibration Workflow

Calibrating a dental monitor with CalMAN Dental is a quick and easy process that takes less than ten minutes to complete. The Dental Display Calibration workflow in the CalMAN software prompts a user to properly position the light meter over the target window on the monitor screen (Figure 6). An outline of the workflow is viewable by opening the left hand CalMAN panel (Figure 7).
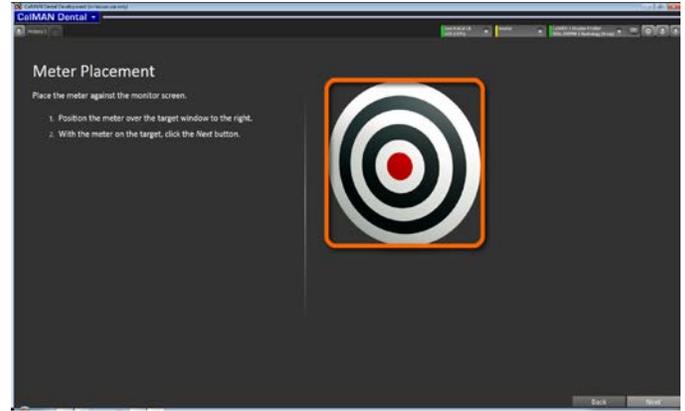

Figure 6: One of the first CalMAN Dental workflow pages prompts the user to position the meter over the target window. CalMAN then initiates automatic display calibration.

After CalMAN checks the placement of the meter, the Metered Calibration section of the workflow then automatically steps through calibrating two monitor profiles. CalMAN first calibrates the monitor for optimum presentation of sRGB color images, saving the calibration data to the Video (sRGB) monitor profile. It then automatically calibrates the monitor for optimum presentation of X-ray radiographs and saves the calibration data to the Radiology (X-ray) monitor profile.
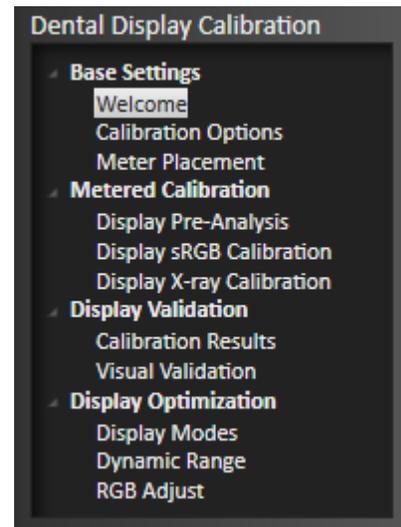

Figure 7: After a couple of initial settings, CalMAN automatically performs the calibrations in the Metered Calibration section of the workflow. It then presents the Calibration Results page.

When the automated calibrations are complete, CalMAN presents the user with the Calibration Results page (Figure 8). If the calibration results are indicated to be passing, the user can click the Save/Report button to save the calibration session and view or print the calibration report.
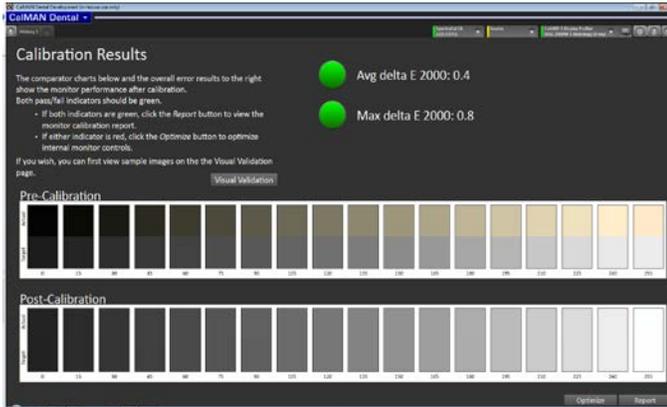

Figure 8: The Calibration Results page shows pass/fail indicators for the monitor's average and maximum values of post-calibration delta error. It also shows a visual comparison of pre-calibration and post-calibration match to grayscale targets across the luminance range.

If the internal monitor controls were misadjusted to the point of causing failing calibration results, the user can click the Optimize button to step through the optional Display Optimization section of the workflow (Figure 7). After the monitor's internal controls are optimized, the Metered Calibration section of the workflow is automatically repeated.

Radiology (X-ray) Profile

CalMAN Dental creates the calibration data for the Radiology (X-ray) profile by implementing industry standard DICOM, AAPM, and ACR radiology imaging guidelines. The luminance level of each part of an X-ray radiograph is corrected to conform to the DICOM Grayscale Standard Display Function (GSDF). This insures that each image level captured by an X-ray scanner is perceivable as a different brightness level on the calibrated monitor.

A part of those guidelines addresses the need for ambient luminance compensation when viewing X-ray images. When creating the Radiology (X-ray) profile, CalMAN automatically elevates the monitor black level to 1.5 cd/m^2. This standard luminance compensation assures that ambient office lighting won't wash out the darker gray levels, eliminating contrast differences in those darker image areas.

Video (sRGB) Profile

CalMAN Dental creates the calibration data for the Video (sRGB) profile by implementing the IEC sRGB color space standard. The sRGB color space is designed to optimize monitors for typical home and office viewing conditions, rather than the darker environment typically used for commercial color editing.

Don't waste time calibrating anything other than the monitor; unlike monitors, today's cameras, scanners, and printers are well calibrated out-of-the-box to the sRGB standard. If you check white balance and exposure on the camera's LCD and save the images as sRGB, the images will have accurate color, saturation, and contrast when viewed on the monitor calibrated with the CalMAN sRGB profile.

Conclusion

The grayscale radiographs and the color photographs that are commonly viewed on dental monitors present a challenge for accurate presentation of both types of images.

To realize the highest diagnostic quality from grayscale radiographs, each image level must be perceived as a different brightness level, as presented on a viewing monitor. CalMAN Dental achieves this by calibrating an X-ray monitor profile for accurate conformance to the DICOM GSDF luminance levels and applying ambient luminance compensation.

To realize the highest diagnostic quality from oral photographs, the sRGB color space must be used to present the standard sRGB images that are created by today's color cameras. CalMAN Dental achieves this by calibrating an sRGB monitor profile for accurate conformance to the IEC sRGB standard.

The X-ray and sRGB monitor profiles are user-selectable thru the CalMAN Client icon to precisely match the performance of the monitor to whichever type of image is currently being viewed.

The Dental Monitor Calibration workflow in the CalMAN Dental software provides a quick, automated process that makes it easy for non-technical users to initially calibrate dental workstation monitors and to routinely recalibrate to correct the drifting effects of monitor aging. CalMAN Dental includes a Dental Calibration Certificate to document a monitor quality assurance program.

References

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Tom Schulte is Product Development Manager at SpectraCal. Tom has extensive experience in electronic systems test, calibration and service, as well as electronics test instrument design and usage and has authored numerous technical white papers. Tom was previously an Application Engineer at Sencore for over twenty years, where he was involved in video, audio, and RF test instrument design, plus training and support for electronic test equipment users.

About SpectraCal:

SpectraCal specializes in the tools and training necessary to achieve images representative of the content creator's intent for environments from low to high ambient light while achieving the colorimetry, contrast, and dynamic range necessary for the image to have the proper impact on the viewer.

SpectraCal CalMAN software was developed to support the display calibrator in the step by step process of screen optimization. The foundation of screen optimization through display calibration is to understand the elements in a display that require adjustment and how each element inter-relates to the others. From its inception, CalMAN has earned rave reviews and has become the preeminent display calibration software package on the market, compatible with virtually all color meters available today. As display technology evolves, CalMAN will continue to provide the first choice for display calibration solutions.

More Information:

For more information on CalMAN professional quality solutions for your displays:

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