White Paper

Advanced Image Quality Stabilization: ColorEdge

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1 Introduction

For graphic professionals, creators and designers who are in critical need to have accurate color reproduction, there are many color calibration LCD monitors to choose from in the market today. These products often highlight that they are factory-adjusted for true and accurate color. However, technically speaking, just performing factory-adjustment to an LCD monitor will not be enough to keep expected color and tone accuracy.

In this technical white paper, we first describe the basic behavior of native LCD panel characteristics focusing on image quality aspects, clarify what is required to overcome these technical challenges for an LCD monitor to maintain accurate image quality, as well as how EIZO ColorEdge series monitors incorporate such technologies to differentiate them from general calibration monitors in terms of the final image accuracy and image quality stability over time.

2 Native LCD Panel Variation and Importance of factory adjustment

EIZO ColorEdge series monitors are adjusted one by one at the factory. Although it is time-consuming and costly work, this is one of the necessary processes to ensure precise and accurate color and tone reproduction. In this section, we will focus on image quality variations on a native LCD panel and explain why it occurs to help you understand how factory adjustment works to eliminate these variations.

2.1 Inevitable image quality variations due to LCD panel structure

An LCD panel module expresses light and dark by controlling the transmittance of light irradiated from a backlight (light source). In recent years, LED backlight has become mainstream as a light source. Due to its technical nature, it is true that LED backlight plays a major role in determining optical characterizes of the LCD panel. However an LCD panel consists of not only an LED backlight, but also many optical material layers such as reflection sheet, diffusion sheet, polarizing plate, color filter and liquid crystal layer assembled. Each raw material has its own tolerances in terms of optical characteristics, and when these are assembled together as a final LCD panel module, even if each component is handled under strict quality control, this generates inevitable optical performance variations within the same LCD panel module.

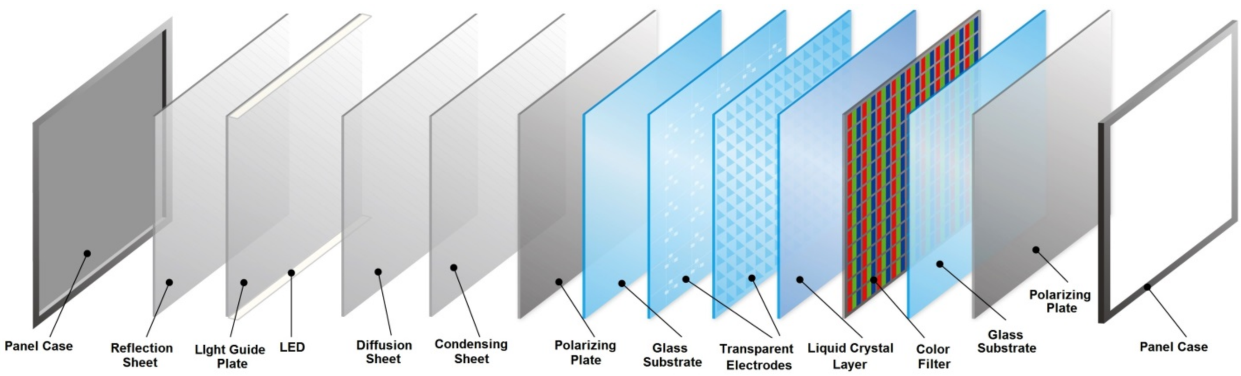

Fig.1 Structure of Liquid Crystal Panel

2.2 Examples of optical characteristic variations on native LCD panel modules

As described in Section 2.1, even in the same LCD panel module, there is a certain level of deviations in optical characteristics. In this section, we will take a closer look at major characteristics that affect to final image quality. Here we pick up and visualize key optical characteristics regarding aspects of image quality – chromaticity (Fig.2), tone characteristics (Fig.3) and luminance uniformity across the screen (Fig.4), which has relatively large variations coming out of the factory even on the same LCD panel module.

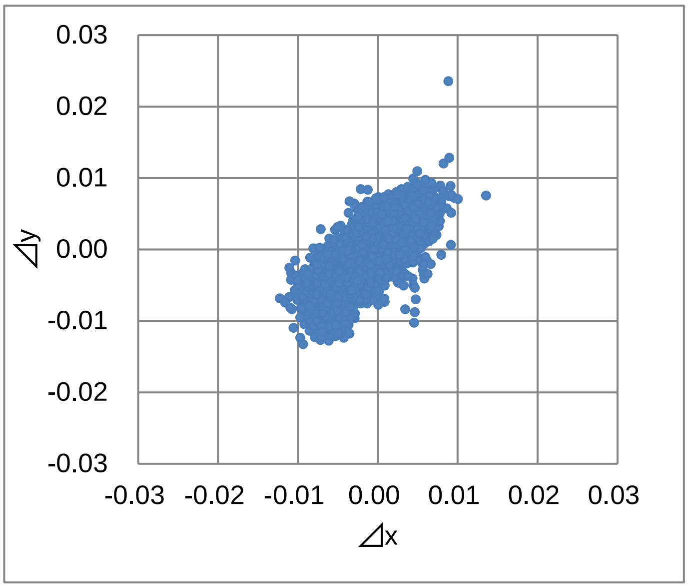

Fig.2 Variation in chromaticity (based on average)

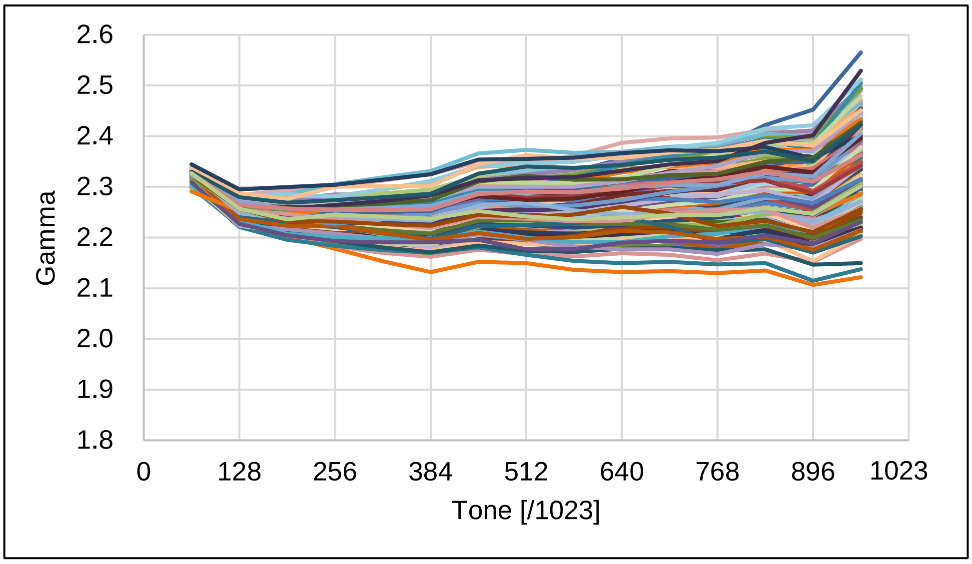

Fig.3 Variation in tone characteristics (gamma)

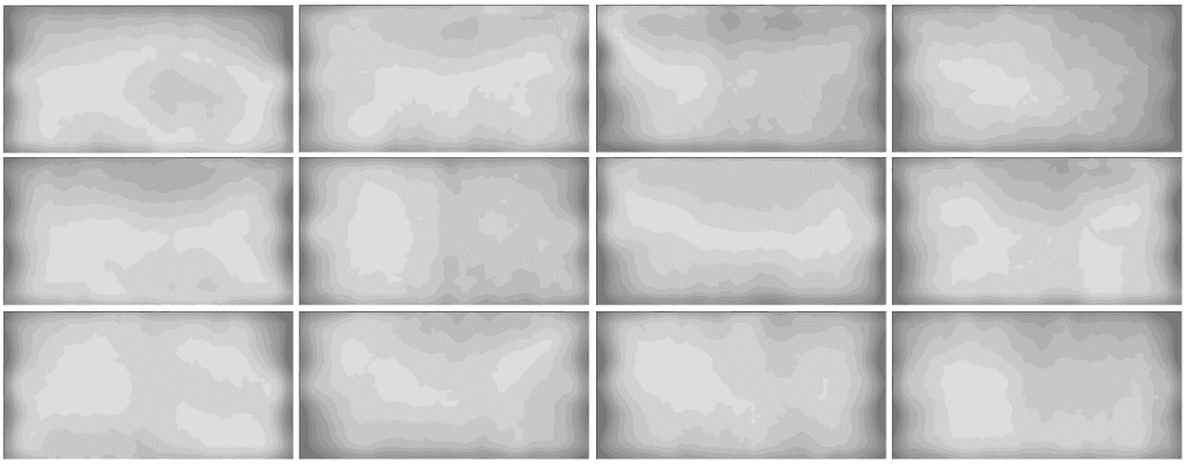

Fig.4 Variation in luminance uniformity across the screen (1023 tone)

These variations on the native LCD panel characteristics result in noticeable color and/or tone differences, even when comparing two equivalent products as shown in the following photo (Fig.5).

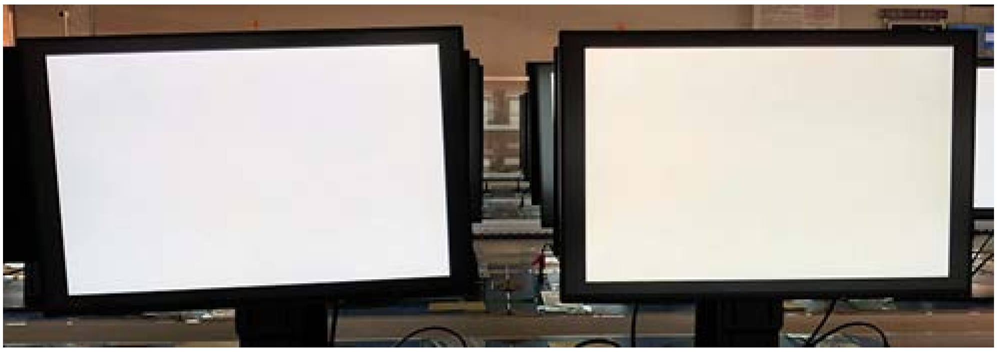

Fig.5 Deviations on unadjusted, native LCD panel modules

Therefore, in order to precisely and accurately display colors as well as to ensure consistent image quality across the same product, it is necessary to perform factory adjustment to correct individual native LCD panel variations such as in luminance level, chromaticity, tone characteristics, screen uniformity etc. one by one. For example, EIZO ColorEdge series monitors are adjusted individually at the factory (Fig.6) by measuring luminance level, chromaticity, every single tone of each RGB channel, luminance and chromaticity uniformity – this achieves highly precise image quality with minimum variation.

Fig.6 Factory adjustment of EIZO ColorEdge series monitors

3 Necessity of display stabilization

In recent years, factory adjustment has become more common among color calibration LCD monitors for color critical applications, but one of the important but less highlighted aspects of the LCD panel characteristics is the fact that optical characteristics fluctuate from time to time when an LCD monitor is in use, and sometimes quite substantially. It is already common knowledge that temperature plays an important part in the cause of this fluctuation of the display characteristics.

In this section, we describe the impact of temperature on image quality fluctuation of an LCD monitor, breaking it down into the following two major phases: monitor warm-up drift and thermal drift after warm-up.

3.1 Warm-up drift

It is already well known that it takes time to stabilize the brightness level after turning on the monitor. However, not only the brightness level, but both chromaticity and gamma characteristics are also affected by temperature change and take a certain amount of time to fully stabilize.

For instance, Fig.7 shows the changes of chromaticity/brightness level in Delta-E 2000* after turning on an LCD monitor without any warm-up drift compensation mechanism. As you see here, there is a considerable chromaticity difference of 5.6 in Delta-E 2000 at 60 minutes after startup compared to the original state. In general, chromaticity difference greater than 2 is known to be noticeable to the human eye. This means that there is an apparant change in color over 60 minutes after startup.

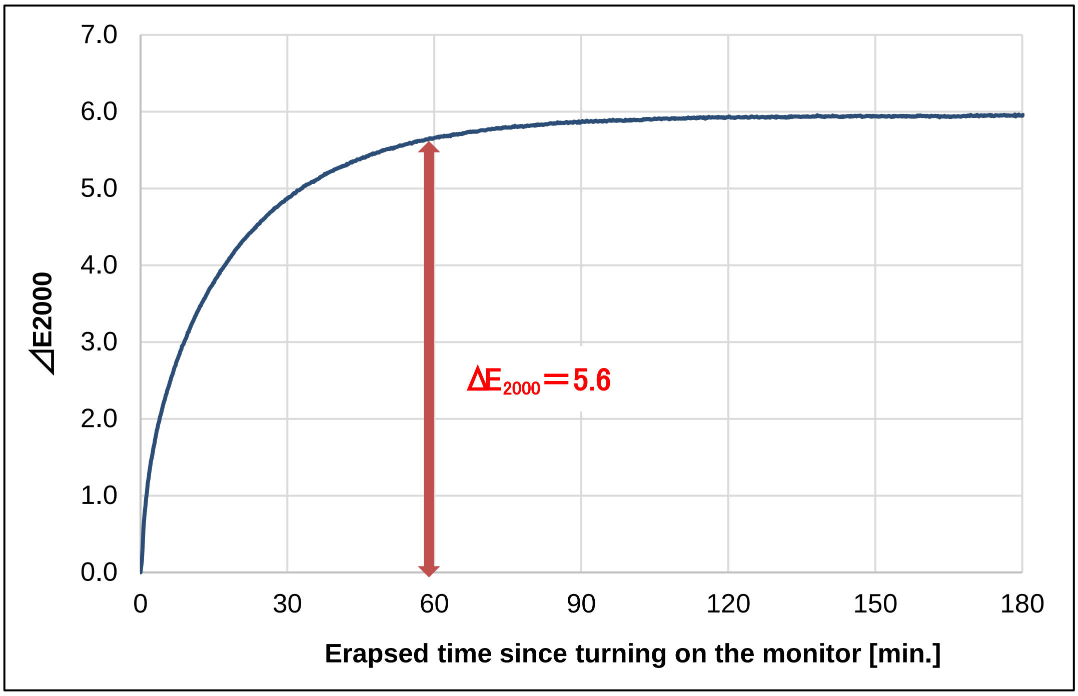

Fig. 7 Warm-up drift in chromaticity and brightness (Benchmark: Timing of turning on)

Fig. 8 shows a drift of the display gamma characteristics at several different signal levels. For accurate color and tone presentation, it is also desirable that the gamma value is constant just after turning on the monitor. But in reality there are several fluctuations in gamma characteristics which have a negative impact on tone accuracy. Taking the gamma value at 640 tone as an example, a gamma shift of 0.1 or greater is observed in the first 60 minutes after powering on.

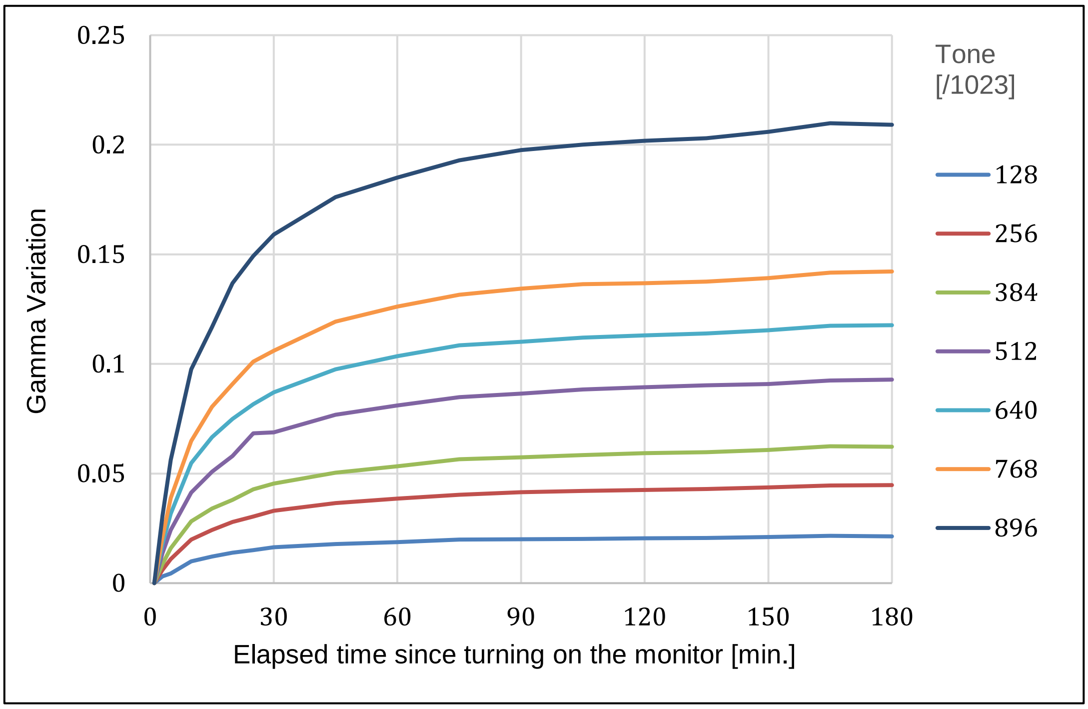

Fig.8 Warm-up drift in gamma value (benchmark: time since turning on)

* [Reference] ISO 11664-6/CIE 014-6 Colorimetry – Part 6: CIEDE2000 Color-Difference Formula 2013
http://www.cie.co.at/publications/colorimetry-part-6-ciede2000-colour-difference-formula

These two results show that changes in color and tone reproduction due to warm-up drift are clearly noticeable and not an acceptable level for color critical applications.

3.2 Thermal drift after warm-up

Even though the LCD monitor is warmed up, the following factors that can affect the internal temperature of the monitor still exist, which have a negative impact on color precision:

- ✧ Room temperature change
- ✧ Switching to different brightness (backlight) level (ex. switch between different color preset modes)
- ✧ Tuning off/on the monitor, entering/exiting from power save mode

Table 1 shows an example of how room temperature affects color accuracy. 10°C increases in room temperature (from 15°C to 25°C) results in a chromaticity and brightness shift of 2.0 in delta E2000, which is noticeable to the human eye.

Table 1 Chromaticity / Brightness Variation (benchmark: 25°C)

Ambient temperature	15°C （-10°C）	25°C （base）	35°C （+10°C）
ΔE_{2000}	2.0	-	1.9

As we discussed in this section, factory adjustment alone is not found to be sufficient enough for precise color consistency on an LCD monitor. Color stability is largely affected by the temperature, and such as when the monitor warms up or room temperature fluctuates during normal use. To avoid this unstable color presentation on an LCD monitor, display stabilization function is a must-have for color critical applications in addition to factory adjustment.

ColorEdge series: stable display　　　General calibration monitor: unstable display

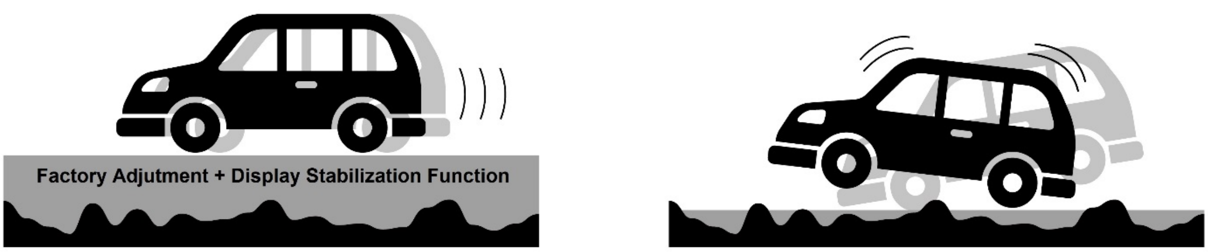

Fig.9 Figurative representation of monitor display quality

4 EIZO's unique advanced display stabilization function

In Chapter 3, we learned that key characteristics of an LCD monitor such as chromaticity, brightness and tone response are constantly fluctuating due to influences from ambient temperature and/or backlight settings which cause temperature changes inside the monitor.

The ColorEdge series incorporates a display stabilization function to minimize these fluctuations, increasing the stability and accuracy of color presentation by correcting unwanted changes on key display characteristics in real time. This Chapter will explain the working principle and the actual performance of the EIZO display stabilization function.

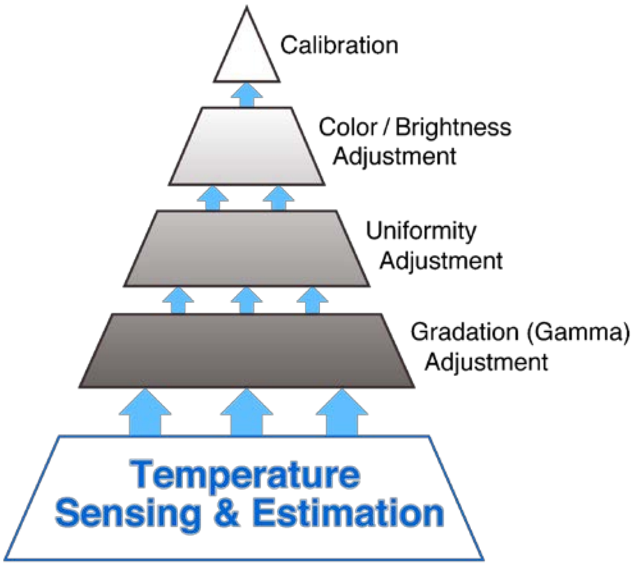

Fig.10 Conceptual diagram of display stabilization

Firstly, the EIZO display stabilization function is composed of three main components:

a) Precise temperature sensing inside the LCD monitor
b) Accurate assessment of temperature surrounding LCD panel module with unique estimation algorithm
c) Real-time feedback loop and adaptive LCD panel control of key image quality parameters

Thanks to this temperature sensing and estimation technology, precise feedback and compensation is performed with high precision in real time to the key elements of image quality – tone characteristics, screen uniformity, and chromaticity/brightness output. This ensures tone and color reproduction are always accurately maintained within the ideal targets which are originally defined at factory.

Explained in the following sections, we tested the performance of the display stabilization function under various temperature conditions also with different brightness settings which resulted in effectiveness for both tone characteristics (gamma) and chromaticity/brightness.

4.1 Tone characteristics (gamma) correction

Fig.11 and Fig.12 compare the tone characteristic fluctuations under various temperature conditions/brightness settings with and without display stabilization. In these graphs, tone curve characteristics in each temperature condition/brightness setting are presented as a different color line. Ideally, when tone curve characteristics would have no fluctuation, the lines would be right on the horizontal axis at gamma 2.4.

Fig.11 shows the Gamma curve deviation without display stabilization, under the influence of temperature change, the gamma fluctuates more than ± 0.1 from 2.4 in the mid to high tone area. In contrast, with the display stabilization function (Fig.12), the gamma deviation is within the variation of ± 0.05 – this shows that the display stabilization function works effectively to maintain accurate tone characteristics, countering changes caused by temperature fluctuations.

- Gamma curve fluctuation vs. various temperature/brightness setting

(γ=2.4 as the target value)

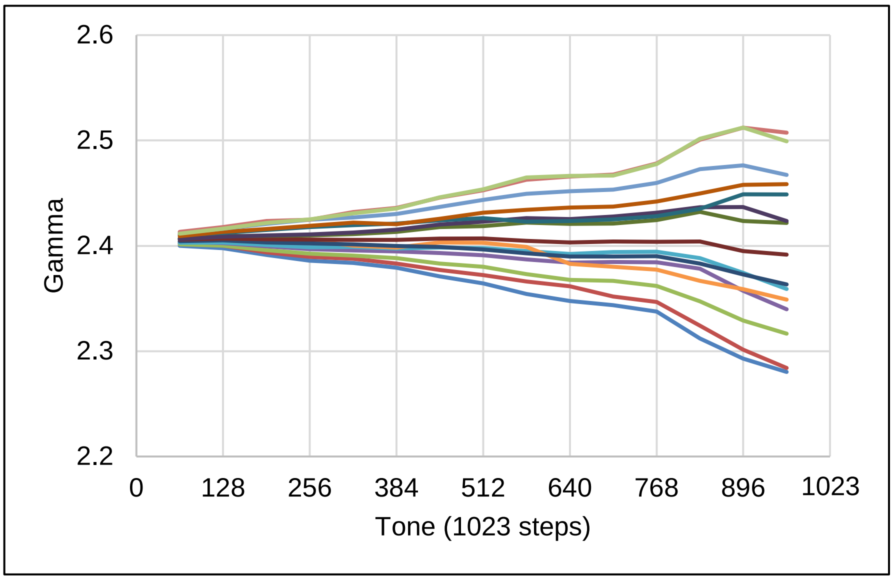

Fig.11 Gamma curve deviation without display stabilization

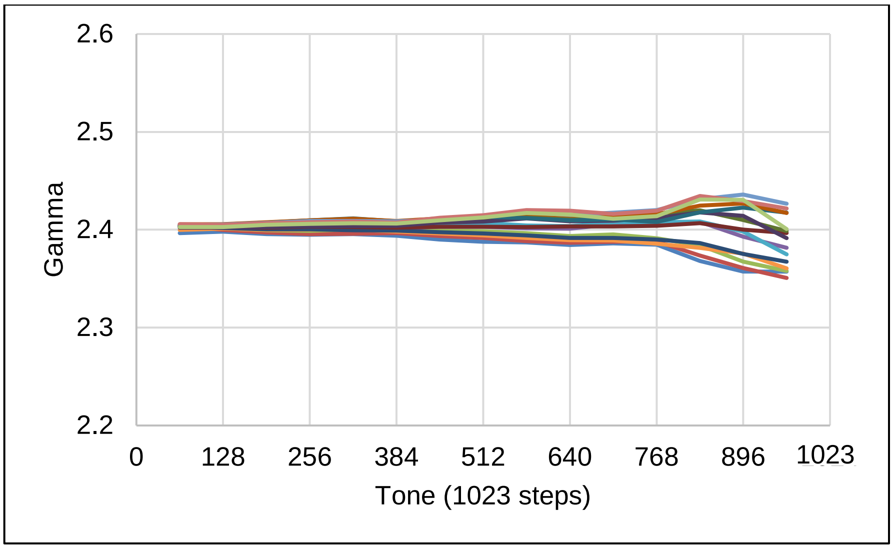

Fig.12 Gamma curve deviation with display stabilization

4.2 Color and brightness correction

As shown in Table 2, without the display stabilization function, when the ambient temperature changes from 25°C to 15°C, there is a variation of ΔE_{2000}=2.0 compared to 25°C. When the ambient temperature increases from 25°C to 35°C, there is a variation of ΔE_{2000} =1.9. In contrast, with the display stabilization function, the variation is minimized to ΔE_{2000}=0.2 at 15°C and 0.4 at 35°C (10 degrees decrease/increase), which shows that the display stabilization function works effectively to maintain chromaticity/brightness stable, countering changes cause by ambient temperature fluctuations.

Table 2 Changes in Chromaticity and Brightness (ΔE_{2000}, benchmark: 25°C)

Ambient Temperature	15°C (-10°C)	25°C (benchmark)	35°C (+10°C)
Without Display Stabilization Function	2.0	-	1.9
With Display Stabilization Function	0.2	-	0.4

5 Display stabilization function enhanced by artificial intelligence (AI)

In order to enhance the performance of the display stabilization function described in Chapter 4, a new algorithm powered by AI is implemented in our latest ColorEdge series (June 2018: CG3145, CG319X). Using a temperature-controlled test room and highly accurate measuring devices, data sets comprised of patterns of subtle changes in the LCD monitor caused by temperature fluctuations are collected and used to train (deep learning techniques) and optimize the AI. This enables the creation of a highly precise ambient temperature estimation algorithm. By utilizing this AI-powered temperature estimation algorithm, the ColorEdge series achieves remarkable advances in display image quality stabilization.

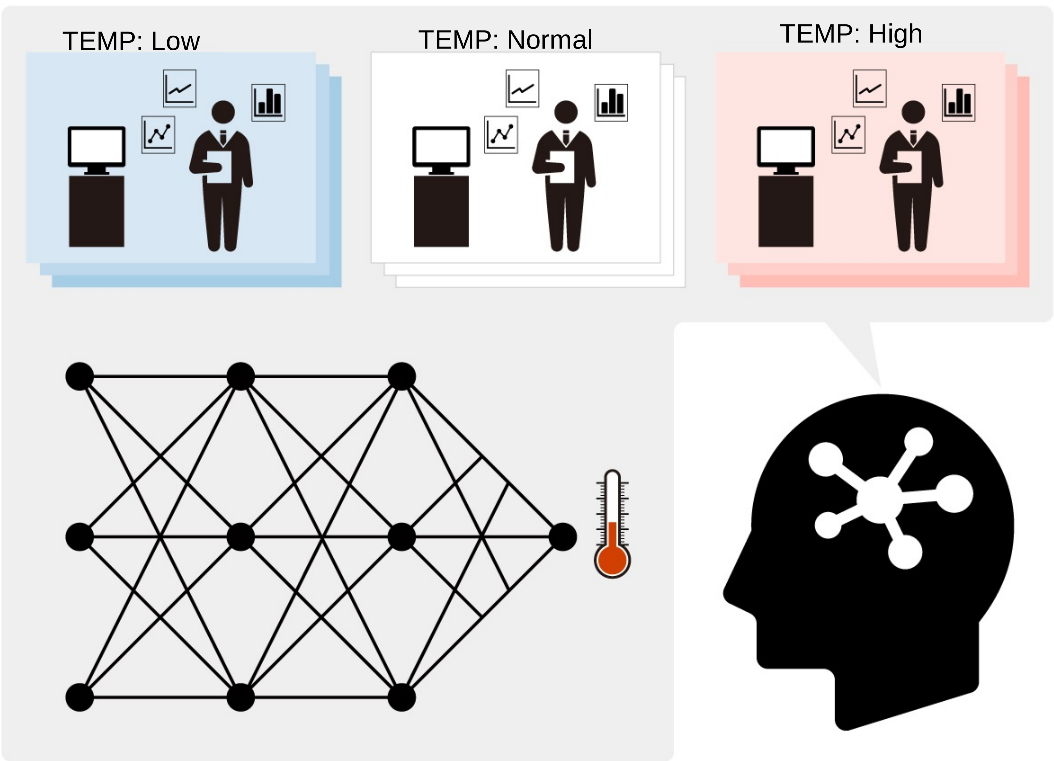

Fig.13 Conceptual diagram of AI-powered temperature estimation algorithm utilizing deep learning techniques

6 Conclusion

There are image quality variations within native LCD panels due to the nature of optical characteristics of each component and its layered structure. For this reason, factory adjustment to an individual product is a mandatory process for minimizing variations and achieving high-precision image quality for color calibration LCD monitor. However, key image quality characteristics such as chromaticity, brightness, and tone curve characteristics continue to fluctuate while LCD monitor is in use due to the influence of temperature. Since this fluctuation is not at a negligible level for color critical applications, display stabilization methods are an inevitable necessity for professionals using a color calibration LCD monitor.

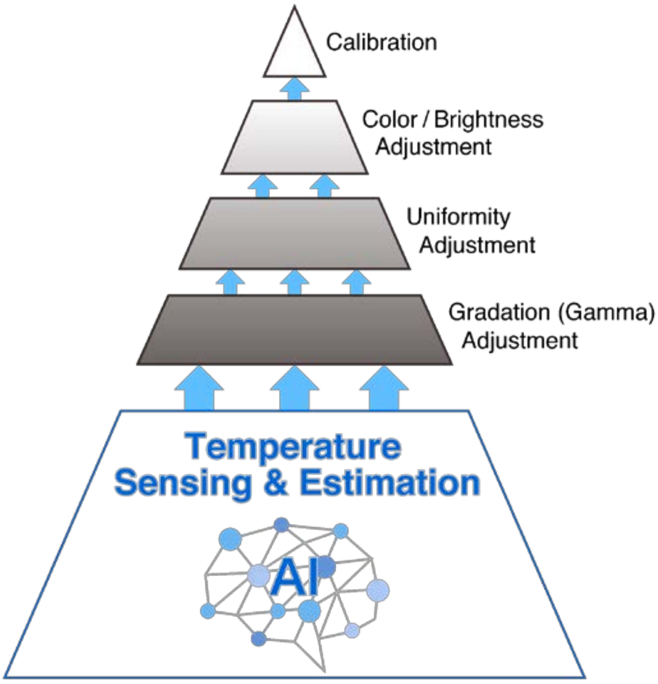

Fig.14 Conceptual diagram of display stabilization

EIZO ColorEdge series monitors incorporate advanced display stabilization functions to avoid these unwanted fluctuations, ensuring consistently accurate color reproduction.

Furthermore, in the latest EIZO models, a temperature estimation algorithm powered by artificial intelligence (AI) enhances accuracy of the display stabilization function.

In conclusion, color calibration LCD monitors which only utilize factory adjustment cannot be considered sufficient enough to ensure color precision for color critical applications. As discussed in this white paper, the display stabilization function is indispensable for always maintaining high image quality at the ideal targets. Unlike generic “color calibration” LCD monitors, EIZO ColorEdge series monitors are engineered not only with highly accurate, individual factory calibration, but also with advanced display stability functions, which make the ColorEdge series completely unique and enable EIZO to offer the ultimate color-accurate solution for color professionals.