KONICA MINOLTA | SENSING ASIA

THE STANDARD IN MEASURING LIGHT

Lighting Technologies, Principle, and Measurement

Contents

Lighting Technologies Principle and Measurement

Color-Rendering Properties

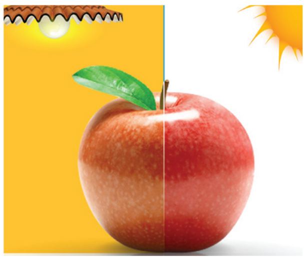
Color Temperature

Light Distribution

Total Luminous Flux

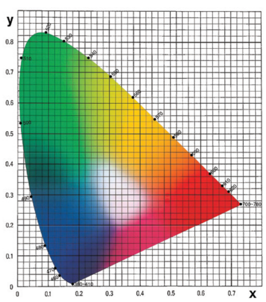
Mura

LIGHTING TECHNOLOGIES, PRINCIPLE, AND MEASUREMENT



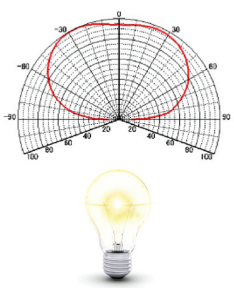
Color Rendering Properties

Learn what color-rendering properties are and see for yourself the relationship between color-rendering indexes and how samples look under different light sources.



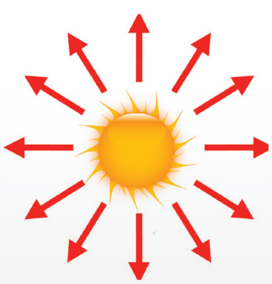
Color Temperature

Learn the correlation between color and temperature, and see the difference from color temperatures measured using a photographic color meter.



Light Distribution

Learn what light distribution is from real-life examples and see how to measure it.



Total Luminous Flux

Learn what total flux is and see how to measure it.

Mura (Nonuniformity)

Learn about mura standards and current measurement methods. Also, see some examples of measurement results obtained using a measuring instrument.

COLOR-RENDERING PROPERTIES

Since long ago, man has compared colors by arranging objects side-by-side and looking at them under natural light (sunlight). Although torches, candles, incandescent lamps and other light sources are also used for illumination, it has always been the standard practice to compare colors under natural light.

In addition to fluorescent lamps, LEDs (light emitting diodes) have recently been adopted as illuminating lamps. When comparing how objects look under these new types of lamps against how they look under natural light, how closely they match is called the “color-rendering property.” A lamp that produces a hue similar to that of natural light is said to have a good (high) color-rendering property.

Today, appliance stores offer many types of lamps (incandescent, fluorescent, LED, etc). Further, fluorescent lamps and LED lamps come in tones like “white,” “warm white,” etc.

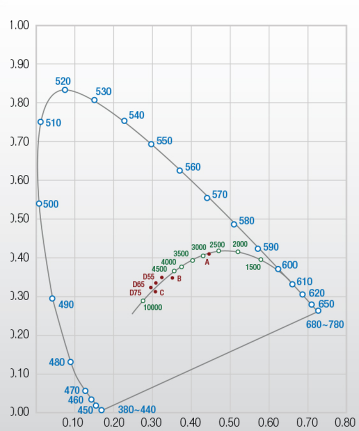
In the examples here, we illuminated an object with a D50 fluorescent lamp with good color-rendering property, a fluorescent lamp that was labeled as “Natural white” and an LED lamp.

To the eye, they all seem white but the natural white fluorescent lamp has a slightly higher color temperature and looks slightly bluish.

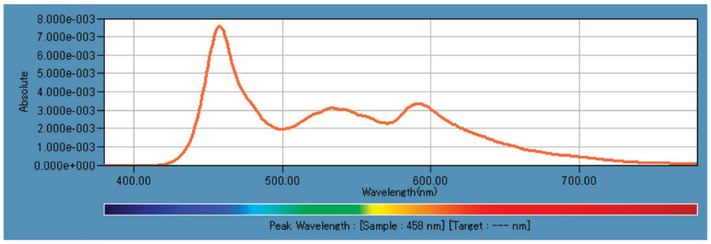
D50 fluorescent lamp | Natural white fluorescent lamp | LED lamp

The hue changes under different lightintg

We measured the three light sources by mounting a luminance adapter on the Konica Minolta Spectroradiometer CS-2000. If you compare the measured points on the xy chromaticity diagram at right, you can see that the tones are similar and in the visible range.



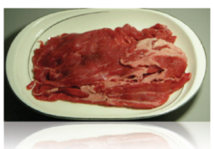
	D50 fluorescent lamp	Natural white fluorescent lamp	LED lamp
X	0.3407	0.3372	0.3465
Y	0.3518	0.3496	0.3662
Correlated color temperature	5173	5308	5004



Spectral distribution of D50 fluorescent lamp, natural white fluorescent lamp and LED lamp Relative intensity

D50 fluorescent lamp

Natural white fluorescent lamp



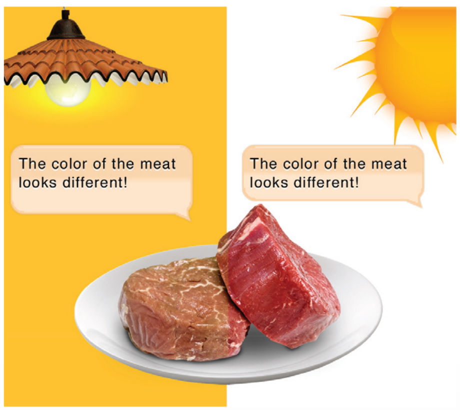
LED lamp

Next, let's illuminate raw meat with the three light sources and see how the meat looks.

Under the D50 fluorescent lamp, the meat and the plate look like they actually do, but under the natural white fluorescent lamp, the color temperature is slightly higher and both the meat and the plate look slightly paler. Under the LED lamp, everything is darker.

- The luminance at the sample surface was adjusted to be about 1600 lux for all three light sources.
- When a sample is illuminated with different light sources, the color may look different.
- The difference in lamp performance is called using a "color-rendering index."
- This index indicates how 15 test colors look under a particular irradiated light.
- When comparing a light source against a stipulated reference light source, an index of 100 is the best.

*Because of its low color-rendering index, the LED lamp used this time made the meat and plate look dark, but the meat and plate can look fresher with an LED lamp having a higher color-rendering index.



We obtained the following color-rendering indexes from the spectral distribution measured with a Spectrophotometer CS-2000 modified for luminance measurement. It can be easily computed using the Data Management Software CS-S10w for the CS-2000.

	Ra	R1	R2	R3	R4	R5	R6	R7
D50 fluorescent lamp	91	94	91	86	90	93	89	90
Natural white fluorescent lamp	79	89	89	54	82	81	72	86
LED lamp	68	65	74	79	68	65	62	81

	R8	R9	R10	R11	R12	R13	R14	R15
D50 fluorescent lamp	90	77	78	93	81	93	92	91
Natural white fluorescent lamp	76	16	40	63	55	92	70	92
LED lamp	54	-39	36	61	31	66	88	59

Ra is the "mean color-rendering index." It is the average of indexes R1 ~ R8 and is a representative value of color-rendering indexes.

R9 ~ R15 are termed "special color-rendering indexes," with particular interest often being shown in R9 (highly vivid red) and in R15.

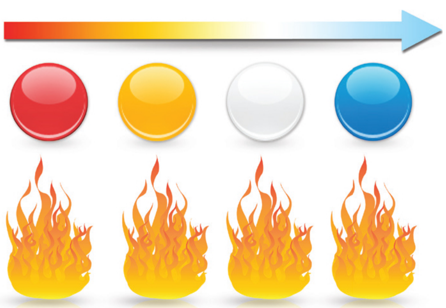
R9 is used for evaluation of the reproduction of red, and the big differences in values between the three types of light sources also give an indication of how much the color of the meat seen under the different light sources will vary.

COLOR-RENDERING PROPERTIES

COLOR TEMPERATURE

As you know, the twinkling (fixed) stars in the evening sky have a faint color. It is also known that the surface temperature of bluish stars is higher than the surface temperature of reddish stars.

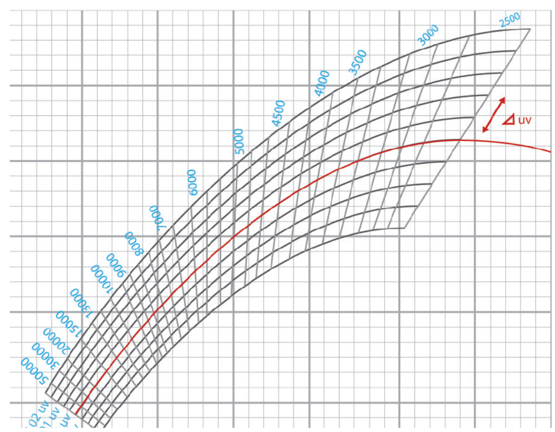
Blacksmiths judge the temperature of a hot iron from its color (red). This should give you an idea that some sort of correlation exists between color and temperature.

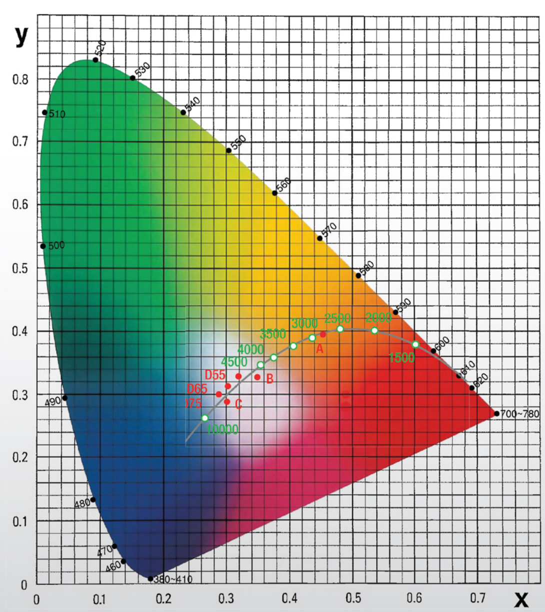


An ideal radiator (blackbody) absorbs all external electromagnetic radiation and re-emits the radiation. As the temperature of a blackbody increases, it changes color in the order of red → yellow → white → blue white.

If this change in color due to temperature is plotted on an xy chromaticity diagram as shown to the right, it looks like the black curved line in the lower center of the diagram. This line is called the “blackbody locus” and the color temperatures on this line are called “absolute color temperatures.”

But not all existing light sources are on this blackbody locus. In fact, most light sources having a white chromaticity point are slightly off of this blackbody locus. In such cases, the color temperature can be obtained using the isotemperature lines drawn across the blackbody locus. The color temperature is then referred to as “correlated color temperature.”





Color temperature and correlated color temperature are generally used as an index to represent colors within a range of white (reddish white, yellowish white, white and bluish white) and can be measured with our Chroma Meter CL-200/ CL-200A (for illuminance and chromaticity measurement), Chroma Meter CS-200 (for luminance and chromaticity measurement), Spectroradiometer CS-2000/2000A and 2D Color Analyzer CA-2000.

DIFFERENCES FROM COLOR TEMPERATURE MEASURED USING A PHOTOGRAPHIC COLORIMETER

Photographic colorimeters are separate from the above industrial-grade measuring instruments. Although they claim to measure color temperature, the purpose is to determine the appropriate filter values for taking pictures. The color temperature taken with such colorimeters is called “photographic color temperature.” Although the sensors of the industrial instruments described earlier are intended to closely match the sensitivity of the human eye, the sensors of photographic colorimeters are similar to the sensitivity of color photographic film.

Fig. 1 below on the left shows the sensitivity of the human eye, and Fig. 2 below on the right shows the sensitivity of color photographic film. You can see that they are completely different.

Because of this, if, for example, the color temperature of the same light source was measured with a Chroma Meter and a photographic colorimeter, the result would be two completely different values.

When measuring color temperature for purposes other than taking pictures, an industrial measuring instrument is needed.

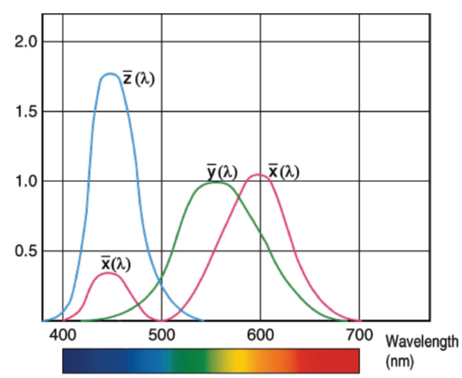


Fig.1: Relative spectral response of the human eye

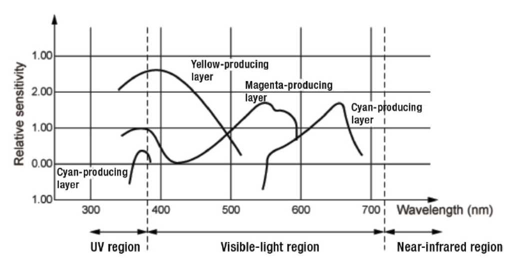


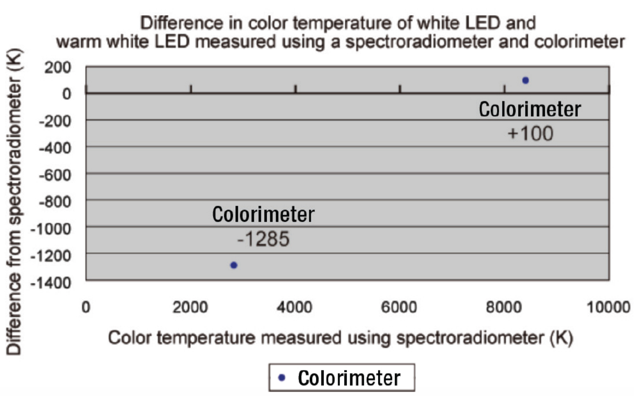
Fig.2: Example of spectral sensitivity of color film

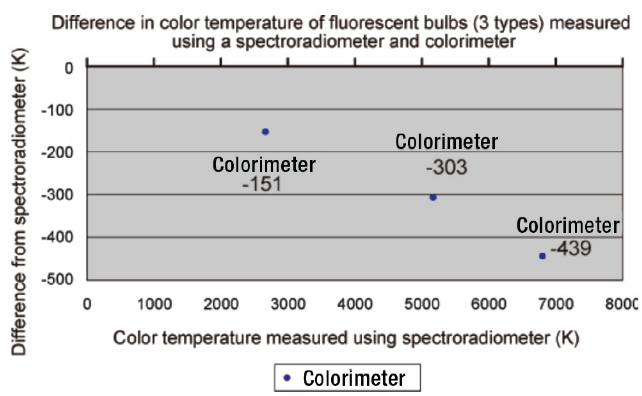
LED bulbs, fluorescent lamps, etc. **Industrial instrument**

Photography **Photographic colorimeter**

As a reference, the graphs below show the results of a comparison between the correlated color temperature of a white LED, colored LED and fluorescent lamp (warm white, natural white and daylight white) measured using our Spectroradiometer CS-2000 + Luminance adapter and the color temperature measured using a photographic colorimeter. The horizontal axis is the correlated color temperature measured using our Spectroradiometer and the vertical axis is the difference in measured values between the spectroradiometer and photographic colorimeter.

You can see that there are wide differences in measured values with some light sources. The correlated color temperature measured using the Spectroradiometer is, in principle, near to the true value. But it should be noted that this is just one example. It is not guaranteed that the same results would be obtained if a different photographic colorimeter were used or even if the same sample were measured using another photographic colorimeter of the same model as that used this time.





Related standard: JIS Z 8725 Methods for Determining Distribution Temperature and Color Temperature or Correlated Color Temperature of Light Sources

LIGHT DISTRIBUTION

All light sources emit light, but in what direction (angle) that light travels and how strong it is are collectively described as the “light distribution.”

Light distribution properties are used to determine what light source would be good for, for example, a strongly directional light or a diffused light. With lighting fixtures and the like, they are similarly measured and evaluated together with light sources, shades, background deflector panels, etc.

With fluorescent fixtures, the light distribution actually includes the effect of parts other than the bulb.

One method for categorizing light distribution is the international method. It defines the light distribution as the ratio of upward moving flux from the light source to the downward moving flux. In this category, the fixture’s configuration can be addressed and a rough idea of the utilization factor, an important factor in lighting design, can be understood.

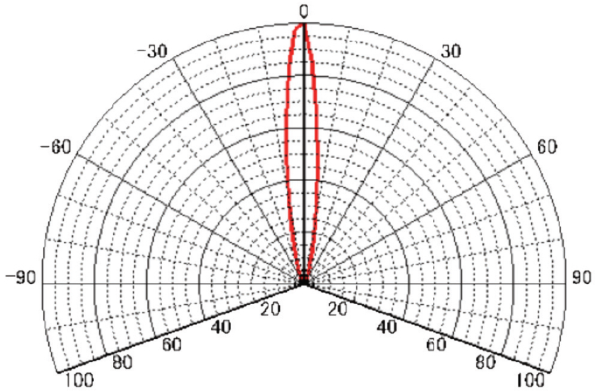


Fig.1: Measured light distribution of bullet LED

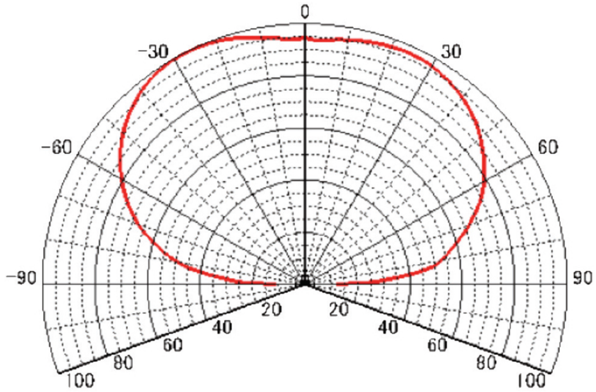
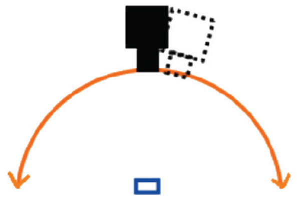
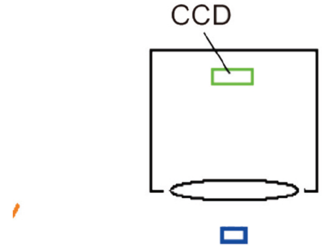


Fig. 2: Measured light distribution of surface-mounted LED

“Light distribution” is defined in JIS Z8113 “Lighting Vocabulary.” That definition reads: “the angular change or distribution of luminosity of primary light sources, secondary light sources (including light transmission and reflection of optical materials, etc.) and lighting fixtures.” As examples, Fig. 1 on the left above shows the measured light distribution of a bullet LED and Fig. 2 on the right above shows the same for a surface mounted LED.

HOW TO MEASURE LIGHT DISTRIBUTION

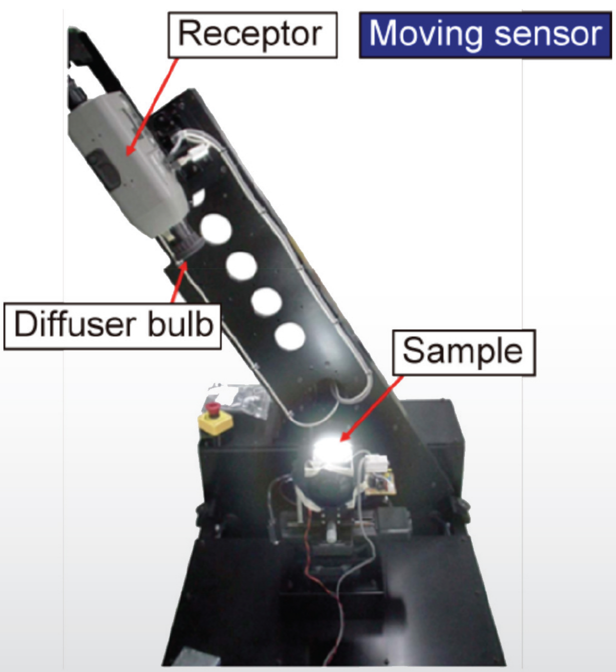
Lighting distribution measurement is basically divided into two approaches. One is to position sensors a certain distance from a sample and measure the light distribution. In this case, results are obtained by measuring from multiple points concentrically located around the sample

	Moving Sensor	Stationary Sensor
Illustration		
Merits	• Angle pitch and sensor distance can be freely set. • Less expensive than a stationary sensor setup	• Short time required to complete all measurements
Demerits	• Long time required to complete all measurements	• More expensive than a moving sensor setup • Restricted by sample shape and size

The other approach is to measure distribution at different distances from the sample using a measuring device consisting of a CCD sensor and an optical system with an extremely wide-angle lens similar to a fisheye lens.

LIGHT DISTRIBUTION MEASUREMENT DEVICE

Konica-Minolta created a customized light distribution measurement device with a moving sensor to meet customers' needs. In addition, three types of sensors can be used: spectroradiometric sensor, colorimetric sensor and luminance sensor.

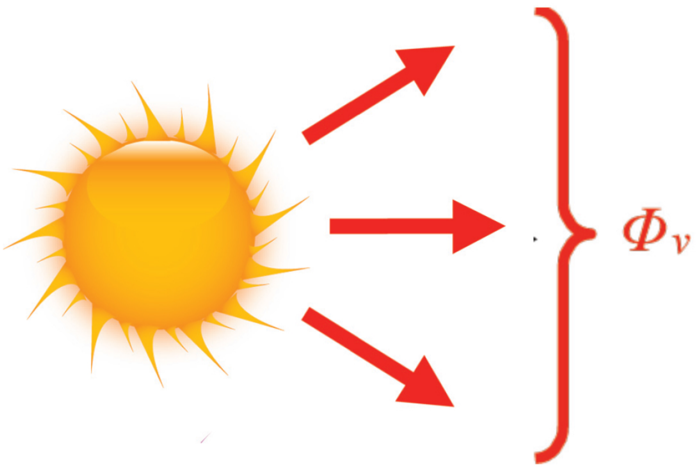


Source: Textbook for Lighting Fundamentals Class, Illuminating Engineering Institute of Japan

TOTAL LUMINOUS FLUX

Luminous flux is a value for evaluating the radiant flux based on the spectral luminous efficiency function of the human eye and the maximum luminous efficacy. Total flux is the luminous flux radiated in all directions from a light source and it is used as a measure of brightness for lighting fixtures. Its units are Lumens (lm).

The terms “luminosity” and “brightness” are often heard to express a quantity of light. Both of these terms include the meaning of directionality. Total flux does not have any connotation of directionality.



$\Phi V = Km \cdot \int \Phi e(\lambda)\, V(\lambda)\, d\lambda$

ΦV: Luminous flux

Km: Maximum luminous efficacy

φe (λ) : Radiant flux

V (λ) : Spectral luminous efficiency

<Examples>

Sunlight: Approx. 3.6×1028 lm

37W fluorescent lamp (White): Approx. 3,100 lm

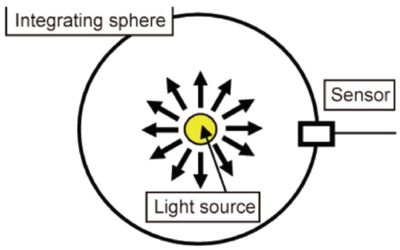
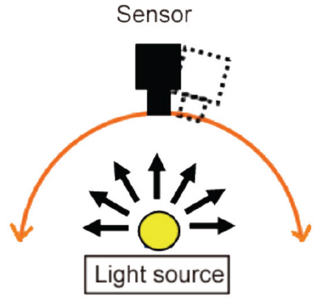
95W white incandescent bulb: Approx. 1,520 lm

Total flux is used in calculations when designing lighting fixtures. “Luminous efficacy of a lamp,” obtained by dividing the luminous flux by the electrical power (power consumption), has also been used from an ecological perspective recently.

HOW TO MEASURE TOTAL FLUX

There are two ways to measure total flux: by using an integrating sphere or by light distribution measurement. The integrating sphere method places a sample light source in an integrating sphere (a sphere that is hollow with the inner wall painted a highly diffusive white color) and receiving the light with a sensor. In this case, the sensor must be calibrated against a reference light source.

With the light distribution measurement method, the sensor is moved concentrically around the sample at a set distance, and the lighting distribution is measured.

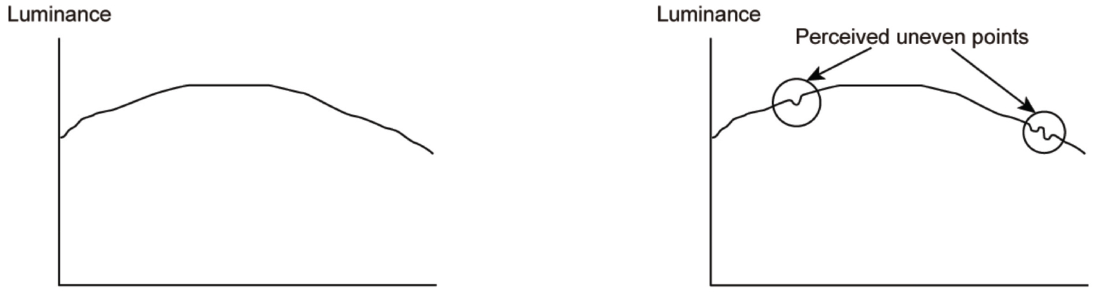
Approach	Integrating Sphere	Light distribution measurement
Illustration		
Merits	• Measurements can be done in a short amount of time. • Simple structure	• Light distribution properties can also be understood
Demerits	• Sensor must be calibrated against a reference light source. • Self-absorption caused by differences in shape from the reference light source must be compensated for in measurements.	• Long time required to complete all measurements • Not suited for samples that radiate light in all directions

TOTAL FLUX MEASUREMENT DEVICE

Konica-Minolta Sensing offers customized integrating sphere and light distribution measurement systems to meet customer needs. (Contact Konica-Minolta Sensing for more information.)

For the integrating sphere method, sphere sizes from 6 to 40 inches in diameter are available.

MURA



Luminance cross-section （Luminance distribution of display seen in a single dimension）

With the larger projection TVs and projectors of recent years, uneven luminance and chromaticity in displayed images readily stand out. “Mura” is a term used to describe the nonuniformity perceived when a person looks at a display.

Luminance cross-section (Luminance distribution of display seen in a single dimension)Perceived uneven points, in the above diagram.

Uneven luminance and chromaticity are each believed to be caused by multiple factors such as contrast, area, etc. Add to this the very big factor of human vision and it becomes very difficult to define it clearly.

MURA STANDARDS

1. SEMU

Despite the difficulty of defining mura, the “SEMU” definition was standardized in 2002. Short for “SEMI Mura Unit,” it was standardized as a unit of measurement by SEMI*. It applies not only to LCDs but also to FPDs. Measurement requires a 2-dimensional colorimeter that not only requires sample luminance to be measured but also the size of the mura area.

*Acronym for Semiconductor Equipment and Materials International, a nonprofit industrial organization to which world-prominent manufacturers of semiconductors, flat panel displays and associated materials belong.

2. JEITA

EIAJ ED-2810 “Measuring Methods for Organic EL Display Modules” released in 2000 by the Japan Electronics and Information Technology Industries Association (JEITA) contains methods for measuring luminance uniformity and white chromaticity uniformity. However, they are based on measured luminance and chromaticity values of an H3 x V3 (9 points) display area; therefore the methods are not effective for measuring mura outside of these 9 points.

CURRENT MEASUREMENT METHODS

Currently there are no standardized rules for measuring mura, but to obtain some sort of objective evaluation, it is better to perform 2-dimensional measurements of luminance and chromaticity using CCD sensors. A 2-dimensional colorimeter for this purpose requires the following functions and performance.

SENSOR WITH SENSITIVITY NEAR TO THAT OF THE HUMAN EYE

Ordinary color CCDs have different sensitivities than the human eye does, making it difficult to measure luminance and chromaticity correctly.

HIGH-RESOLUTION CCD

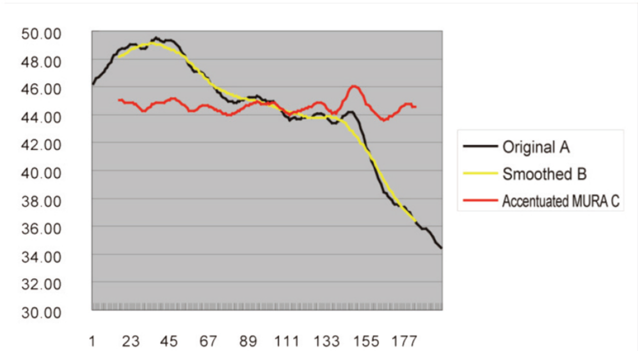
With a resolution of 200×200, for example, the luminance variations of small areas cannot be captured.

LOW SENSITIVITY ERROR PER CCD PIXEL

If mura occurs in the sensitivity of individual CCD pixels, the luminance distribution and chromaticity distribution cannot be accurately measured.

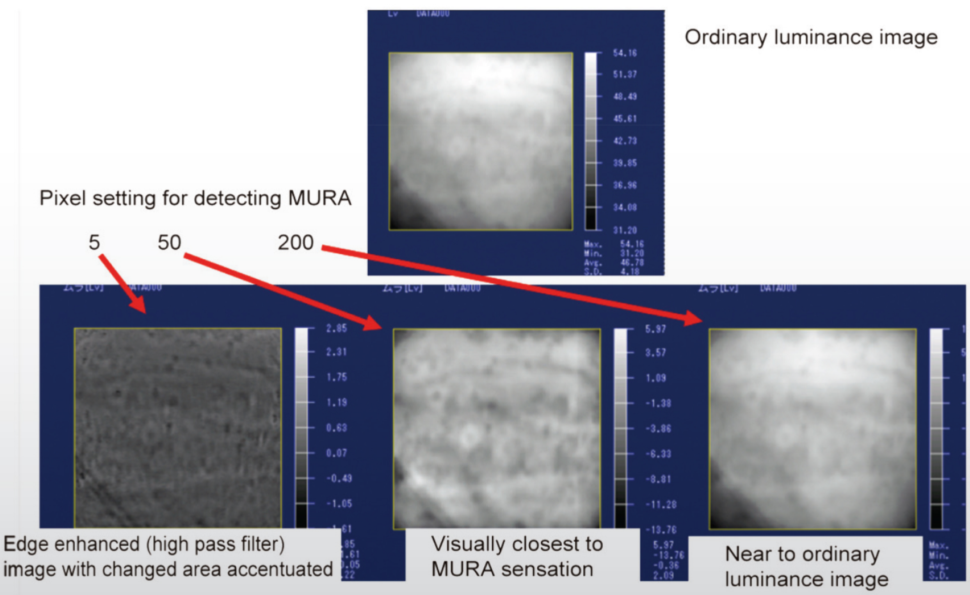
MEASUREMENT DEVICE

Konica-Minolta developed the 2D Color Analyzer CA-2000A with a resolution of 980 x 980, with sensor sensitivity near to that of the human eye and minimal sensitivity error per CCD pixel. The drive software incorporates a function for accentuating mura. This function obtains the average mura of an area of a set size around each measurement point and uses it to smooth the data. It displays the ratio of each measurement point data and averaged data as 2-dimensional results. Therefore, when sample luminance is uniform, it accentuates anywhere within the display where luminance is low or high.



A: Luminance cross-section
B: Moving average of A
C: A / B

EXAMPLE MEASUREMENT RESULTS



MURA