

# Choosing Between RGB and XYZ Color Sensors for Adaptive Lighting Adjustments



## Introduction

The global market for color light sensors is rapidly increasing as customers demand a better user experience with attractive display interfaces. This growth is across various industrial, automotive, and consumer applications such as laptops, tablets, automotive displays, appliances, medical equipment, and human-machine interfaces (HMI). Color light sensors detect the brightness and color wavelength of the incident light, enabling applications to adjust color and brightness based on environmental lighting conditions. The type of color sensor technology used impacts the sensing performance. This article compares the technical differences between RGB and XYZ color sensors and provides a guideline on which sensor to choose for an application.

## Overview of RGB and XYZ Color Sensors

There are two types of color sensors, RGB and XYZ. The XYZ sensor senses a complete standardized color space, while RGB reads an unstandardized subset of the standard color space. RGB then indirectly mapped to the standardized color space for color correction or calibration, which introduces inaccuracies. Choosing one color sensor over the other depends on the application's accuracy requirements.

- RGB: Shown in [Figure 1](#), an RGB color sensor senses an unstandardized color space in which red (R), green (G), and blue (B) values combine to represent various colors. Typically, R, G, and B values range from 0 to 255. A value of 255 for all three colors produces white, and a value of 0 for all three colors produces black. The RGB color space does not have a universal standard making RGB color sensors device-dependent. Different devices detect RGB values differently, and the color measured varies from manufacturer to manufacturer or even in the same device over time.
- XYZ: One of the challenges with RGB is that the unstandardized color space cannot observe all colors, thereby leaving this color space incomplete. CIE 1931 XYZ Color Space Standard, shown as the large curve in [Figure 1](#), can help alleviate this issue. This standardized color space represents all visible colors. This standard is absolute, independent of the device or manufacturer variation, and more accurate and sensitive to color variation than a sensor based on the RGB color space. In addition, the Y channel of an XYZ sensor has a photopic response to extract a value of lux or brightness.

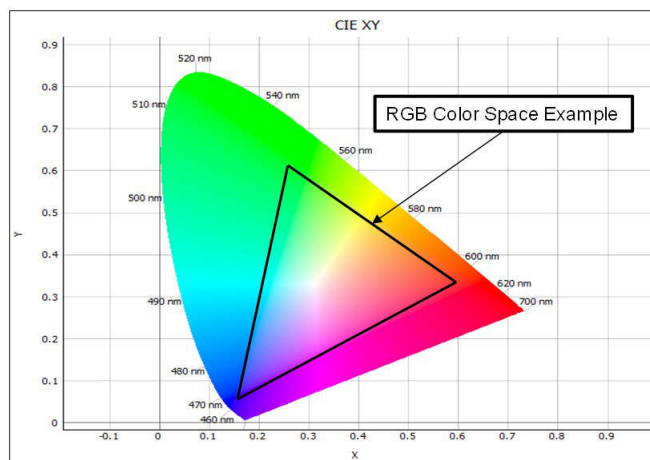


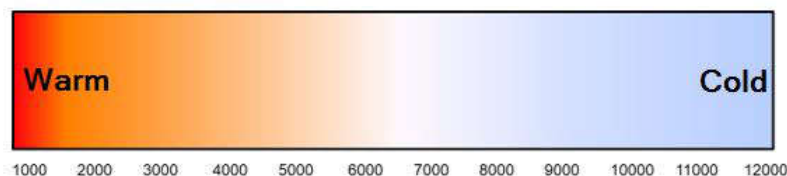
Figure 1. RGB and XYZ Color Spaces Coordinates

## Comparison Between RGB and XYZ Color Sensors

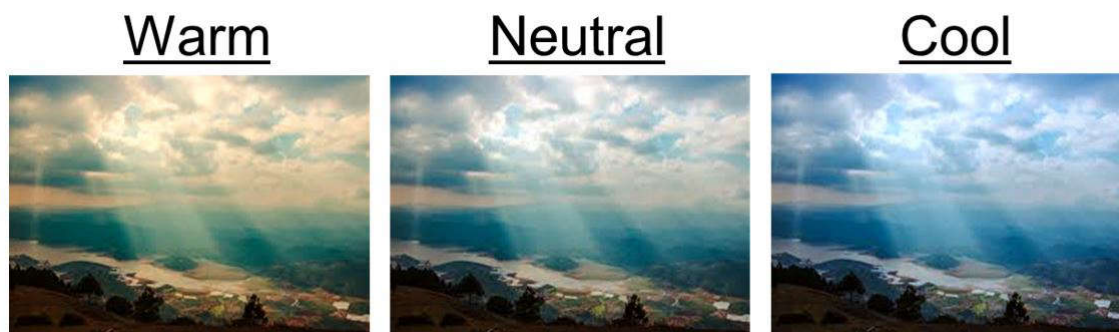
Selection between the two color sensors depends on the application requirements for the accuracy of color measurement. This section discusses the color sensor use cases and compares RGB and XYZ color sensors for each use case.

### Ambient Light Color Sensing

Ambient light color sensing, the detection of environmental light's correlated color temperature (CCT), is one of the most common use cases for color sensors. . Measuring CCT is important because our eyes constantly and automatically adapt to changes in ambient light color, but electronic displays and cameras do not. Without correction, they can produce images that look unnatural or jarring compared to the surrounding environment. The color temperature of a display or lighting system is therefore adjusted based on the ambient light color sensed. Cameras can use CCT for color temperature correction in the output video or images. In most cases, the desired color sensor output is white light. However, for example, the light temperature is warmer outdoors during sunset and cooler during the middle of the day. Display applications use the CCT values, as shown in [Figure 2](#), to adjust the display's color profile so the images seem natural by matching the environment's light temperature. This adjustment improves the visual appearance of displays or camera feeds, as shown in [Figure 3](#), rather than causing a harsh contrast in lighting temperature without the adjustment.



**Figure 2. Correlated Color Temperature (CCT) Spectrum**

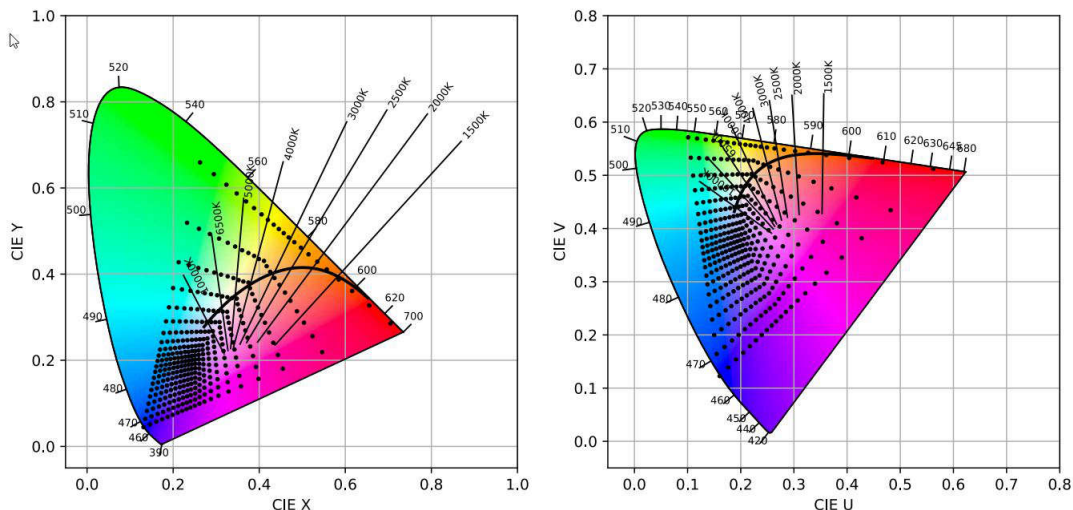


**Figure 3. Example of Warm, Neutral (Sheet of Paper), Cool CCT**

RGB sensors are not standardized and often require calibration to convert the RGB coordinates to the CCT spectrum. There is no straightforward way to determine if a color point maps to the CCT spectrum. While some manufacturers provide a conversion matrix or a simple linear equation to convert RGB color coordinates to the CCT spectrum, the conversion accuracies vary. In addition, non-white light is often mapped to the closest CCT value and provides invalid results. For these reasons, XYZ sensors are preferred for CCT measurement.

XYZ sensors map to the nearest CCT value without calibration. To determine if a color point maps to the CCT spectrum, the common practice is to convert the XYZ coordinates to the UV color space. With a simple equation, determine the distance of the color point from the black body curve. The black body curve represents the color a human eye perceives in CIE YX and CIE UV spaces, shown in [Figure 4](#) when a black body of certain Kelvins emits radiation. The intersecting lines with various kelvin markings are iso-thermal lines representing the same color temperature and are the CCT values. CCT is often valid only around the black body curve and does not make sense when there is too much deviation. Any color coordinates close to the black body curve can represent a particular CCT.

If a cover material such as glass is over the light sensor, RGB and XYZ sensors require calibration.



**Figure 4. CIE XY and CIE UV Space Plots of Color Coordinates**

### Relative Color Matching

Many applications require a color sensor to act as feedback to keep lighting color constant over time. This is known as relative color matching. Rather than measuring the absolute color temperature of ambient light, the sensor monitors whether the color output of a light source has shifted from a known reference point and triggers corrections to bring it back in line.

Overhead lighting control is a common example of a relative color matching application. In these systems, the color sensor continuously monitors the light output and feeds that information back to the lighting controller. If the sensor detects any shift in color from the desired reference point, the controller adjusts the lighting output to correct it, ensuring a consistent light color is maintained across the space.

LED-based lighting systems are another example. Factors such as temperature, driver current, PWM dimming, and aging can cause the color of LEDs to drift over time. To compensate, many LED lighting systems include additional blue and red LEDs alongside the white LEDs. The color sensor continuously monitors the light output and feeds that information back to the system. If the sensor detects that the color point has shifted from the original factory calibration, the system blends in the colored LEDs until the sensed color matches the factory calibration again.

RGB and XYZ sensors are effective in relative color-matching applications without needing color calibration. Since the application only requires detecting a shift from a known reference point within the same color space, the standardized XYZ color space offers no significant advantage. Therefore, an RGB sensor is the more practical choice for these kinds of applications.

### Absolute Color Matching

Some applications require measuring an exact color point, where an objective match between two colors is needed without directly comparing them. This is known as absolute color matching. Unlike relative color matching, which only requires detecting a shift from a known reference point, absolute color matching requires an exact and objective color measurement that can be reliably communicated and reproduced across different systems and manufacturers.

For example, color sensors can determine paint color. Paint changes color over time due to exposure to heat and sunlight. After some time, some sections of a painted surface need patching. The overall paint color has changed from the original color. The new paint matches the current color to avoid standing out. If the color sensor uses the sensor's own color space, such as with an RGB sensor, there is no way to communicate the paint color with other color spaces. The paint manufacturer very likely uses a different color space. Matching the RGB color sensed to a specific manufacturer's paint color is challenging.

XYZ sensors sense color in the standardized CIE 1931 XYZ Color Space. Therefore, even if the paint manufacturer works in a different color space, their color space can convert to the standardized XYZ space.

On the contrary, an RGB sensor often requires a complex calibration to match the two spaces. The color accuracy of the RGB sensor is limited.

### Ambient Light Lux Sensing

Measuring the light intensity value (lux) is desirable in many light-sensing applications. For the best possible user experience, the display brightness adjusts to match the environmental light brightness by using the lux value.

For most RGB color sensors, sensing lux is more complicated and limited, as typically no channel provides a true photopic response, and calibration and a matrix are required. However, some RGB sensors such as the OPT4060 can derive lux directly from the green channel without requiring calibration or a matrix.

In contrast, all XYZ color sensors provide a direct mapping to lux, where the Y channel has a photopic response and is linear to lux. The color sensor manufacturer usually provides a ratio or simple single-point calibration to determine the Y to lux ratio.

### Summary

In summary, RGB color sensors (such as TI's OPT4060) and XYZ color sensors (such as TI's OPT4048) can sense and distinguish different colors. RGB color sensors do not represent the entire visible color spectrum and are dependent on the light source and type, unlike XYZ color sensors. While most applications use either an RGB color sensor or an XYZ color sensor, there are advantages and disadvantages to using either color sensor type. While usually more cost-effective, RGB sensors require additional calibration and transformations, but are typically less accurate when compared to an XYZ sensor. [Table 1](#) summarizes the recommended device for each common use case based on the accuracy requirements and color space needs discussed in this document.

**Table 1. RGB vs. XYZ Comparison Table**

Use Case	OPT4060 (RGB)	OPT4048 (XYZ)	Recommended Device
Ambient Light CCT Measurement	Requires additional calibration to convert RGB values to CCT	Direct CIE XYZ-to-CCT mapping	OPT4048
Relative color matching / LED feedback	Effective for detecting color shifts from a known reference point without requiring color calibration	Effective for detecting color shifts from a known reference point, but standardized CIE XYZ color space offers no significant advantage for this application	OPT4060
Absolute Color Matching	Uses a non-standardized color space, making it difficult to communicate or reproduce color measurements across different	CIE 1931 XYZ is a universal standard, enabling interoperability with any color space	OPT4048
Ambient Lux Measurement	Lux is derived from green channel	Lux is derived from Y channel	Either
Medical / Industrial Color-Critical	Non-standardized RGB color space limits accuracy and interoperability	Standardized XYZ response provides high accuracy for precision applications	OPT4048

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