# White Paper

## ‘True color’ sensors - See colors like a human does

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## introduction

Applications where the color of certain objects has to be securely checked repeatedly present sensors with immense challenges. In particular, the different properties of artificial surfaces make it harder to reliably evaluate color. Why is that? And what solutions are available? In order to come closer to answering these questions, one must first know what abilities the human eye is capable of in the field of color recognition.

Color is a sensation that is caused by external stimuli of the eye. For color recognition, the human eye has different visual receptors: the rods and the cones.

In advanced stages of dusk or almost complete darkness, the 120 million rods of the eye are used, since they have a higher level of sensitivity to light compared to the cones. Here, a person is only able to distinguish between light and dark or black and white.

## ‘normal observer’ determines the average value

However, the six million plus cones in the eye allow for color vision in daylight or upon the arrival thereof. Here, a distinction is made between the (total) three different types of cone, each of which has different spectral sensitivities.

Originally, the relative sensitivity curves of the three types of cones and/or color receptors for seeing red, blue or green were established experimentally. However, as the sensitivity curves of the eyes vary somewhat from person to person, a so-called ‘standard observer’ average was laid down. (Fig. 1)

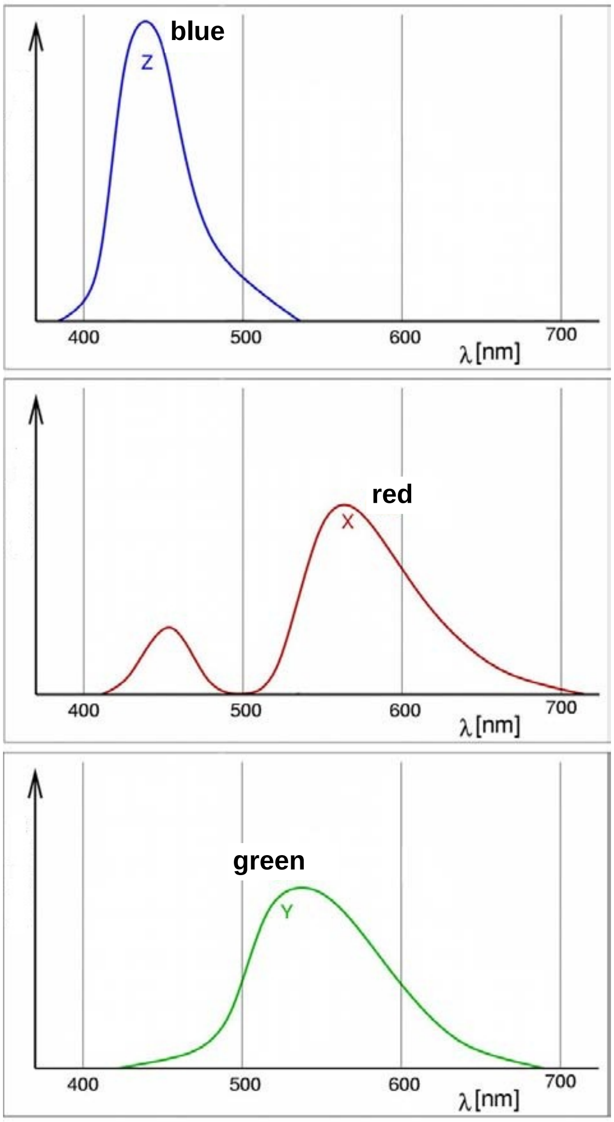



Fig. 1: As the sensitivity curves of the eyes vary somewhat from person to person, a so-called ‘standard observer’ average was laid down.

tristimulus value mapping Y–axis

## different color perception

Perceptions of color are caused by both light sources and illuminated objects. While light sources illuminate automatically due to the electromagnetic radiation emitted from them, objects react differently depending on their composition. As such, objects absorb some wavelengths from the ‘white light’ that impacts upon them. The non-absorbed wavelengths are reflected back in the form of light reflected from the surface. Therefore, the light that is reflected back has a different spectral composition than the light that impacts the surface. If the light is completely absorbed, humans recognize the surface as the ‘color’ black. In addition, the electromagnetic radiation coming into the eye, which is respectively reflected from the object and/or emitted by the light source, is evaluated using the spectral sensitivity of the three types of cones, as illustrated by the example in Fig. 2.

tristimulus value mapping Y–axis

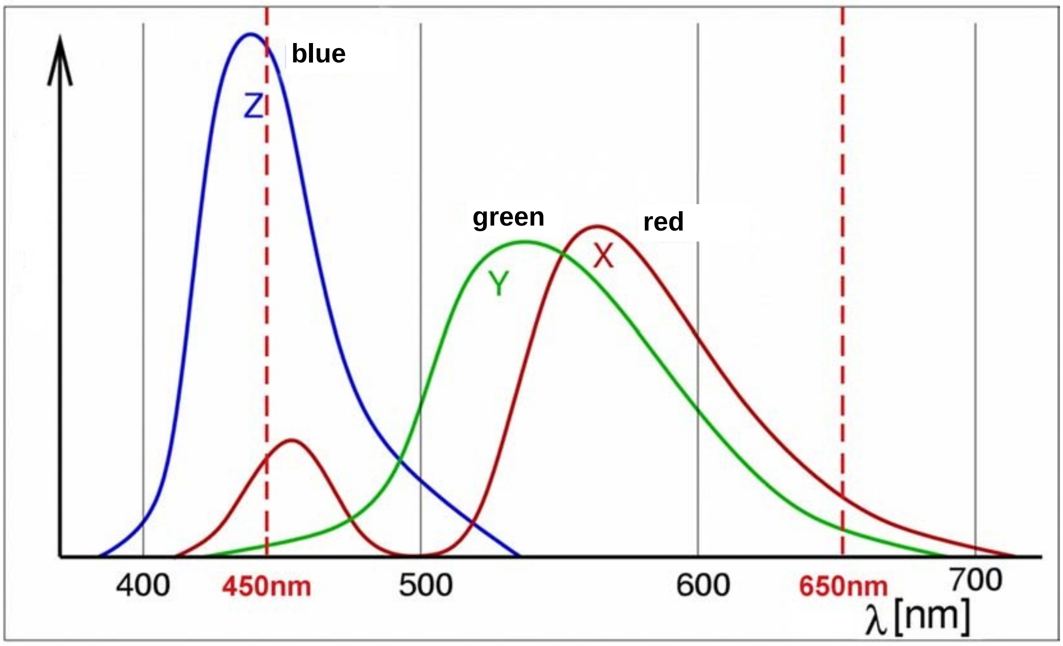



Fig. 2: The radiation of a 450nm wavelength causes a reaction in all three cone types (red/blue/green sensitivity), whereas the radiation of a 650nm wavelength only triggers red and green sensitivity.

## standard colormetric system

In 1931, the International Commission on Illumination (CIE - Commission internationale de l’éclairage) defined the CIE standard color system and/or standard colormetric system for describing color perceptions. The system establishes a relationship between the human perception of ‘color’ and the physical causes of the color stimulus and, in doing so, provides a basis to describe the totality of perceptible colors.

In this system, each color can be represented by triple numbers and/or triple coordinates which stand for the three components of the standardized basic colors (X = red part, Y = green part, Z = blue part). The basic color components are also referred to as standardized color values (tristimulus values).
In order to present a three-dimensional color space (as perceived by a viewer) more clearly, the two-dimensional CIE standardized color diagram was developed. For this purpose, the tristimulus values X, Y and Z are transferred into the so-called tristimulus components x, y and z.

$$x = \frac{x}{x + y + z} \qquad y = \frac{y}{x + y + z} \qquad z = \frac{z}{x + y + z}$$

Because of the relationship 1 = x + y + z, it is not necessary to state the tristimulus component z or show the color type in the two-dimensional tristimulus diagram.

However, the components of the tristimulus values provide information about the nature of the color, but not its brightness. This is why a brightness measure is necessary in addition. (Fig. 3)

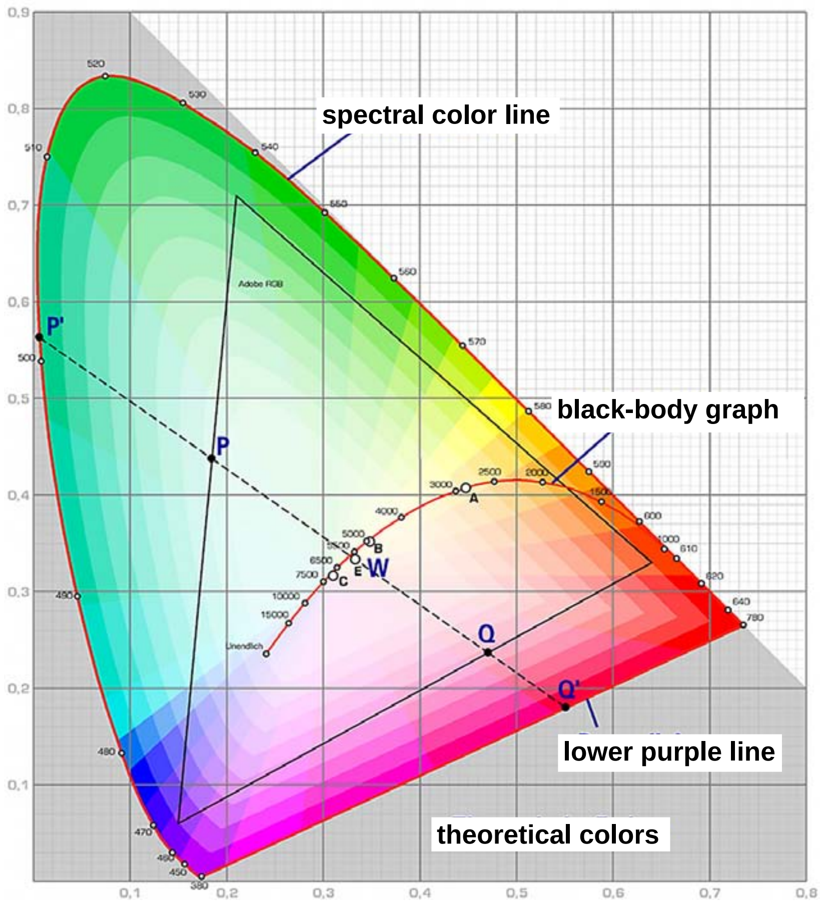



Fig. 3: The totality of possible colors (excluding the light-dark variations) is defined by the spectral color line which borders the horseshoe (spectrally pure colors) and the lower purple line. *Image source Wikipedia: GNU Free Documentation License*

## three-dimensional color system

In order to determine ‘color differences’, however, the standard color chart is not suitable. This is because the distance that is depicted there between two color locations and/or the color coordinates does not reflect the difference one sees when looking at the colors. Therefore, among other things, the CIE developed the L*a*b* color system from the CIE -XYZ three-dimensional model. (Fig. 4)

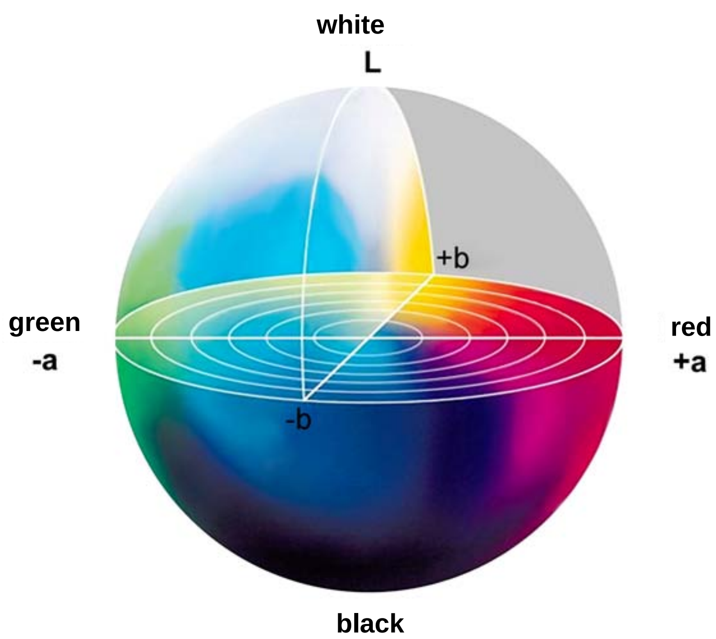



Fig. 4: Three dimensional L*a*b* color system.

The conversion of the X, Y and Z coordinates in the L*a* b* system takes place according to the following formulas:

**brightness:** $L^* = 116 \cdot \sqrt[3]{\frac{Y}{Y_n}} - 16$

**green-red:** $a^* = 500 \cdot \left(\sqrt[3]{\frac{X}{X_n}} - \sqrt[3]{\frac{Y}{Y_n}}\right)$

**yellow-blue:** $b^* = 200 \cdot \left(\sqrt[3]{\frac{Y}{Y_n}} - \sqrt[3]{\frac{Z}{Z_n}}\right)$

The standardization values Xn, Yn and Zn are dependent on the light source that is used (usually in accordance with the EN standard - standard illuminant D65). In many areas, models adapted to specific applications also play a role:

## Other color systems

| | |
|---|---|
| **LMS system:** | the physiological color space builds on the spectral sensitivities of the L, M and S cones |
| **RGB system:** | computer monitors, internet standard |
| **CMYK system:** | desktop publishing, print output |
| **HSV system:** (with the variants HSL, HSB, HSI) | design, painting documentation, video art |
| **LCh° system:** | this does not strictly describe any other color space, but the presentation of HSV, LUV or LAB in polar coordinates |
| **\|1\|2\|3 system:** | technically optimized computing space for image processing |
| **YCbCr system: (sometimes abbreviated to YCC, cf. below)** | digital television and digital PAL as well as digital NTSC, DVB, JPEG, MPEG and DVD video |
| **xvYCC system:** | extended color space in contrast to YCbCr which uses the entire 8 bit per color channel and can be used for new flat screens |
| **YPbPr system:** | analog HDTV, analog component video |
| **YUV system:** | for analog PAL and NTSC |
| **YIQ system:** | an old system, last used with analog NTSC |
| **YDbDr system:** | for analog SECAM |
| **YCC system:** | kodak Photo CD |

## Sensors for 'True color' detection

With a view to 'True Color' detection (seeing colors in the same way as a humans), the OF34, OF50, OF63 and OF65 (Fig. 5) series is a family of color sensors from ipf electronic which are designed specifically for this job. 'True color' detection is enabled through the sensitivities of the integrated sensor receiver for the basic color components (R = red, G = green, B = blue) that have been adjusted to the sensitivity behavior of human sensory cells, specifically the cones. As such, the human ability to see color vision is to a certain extent simulated by the devices, but with the distinct advantage that the evaluation speed is much higher.

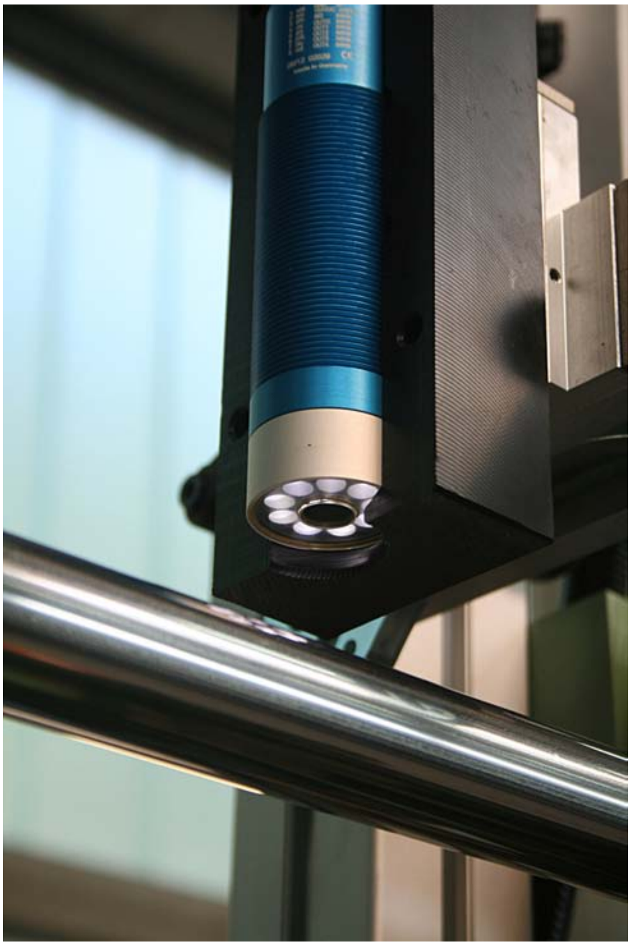


Fig. 5: 'True color' sensor in the OF34 series

The simulation of human color perception is crucial for being able to distinguish even very similar colors using the sensors. This is because, in the case of a ‘true color’ receiver, changes in the radiation (to be detected) always change the signal of at least two receiver elements as well. In conventional color receivers, the signal change may, however, be limited to one receiver. (Fig. 6)

**tristimulus value mapping Y-axis**

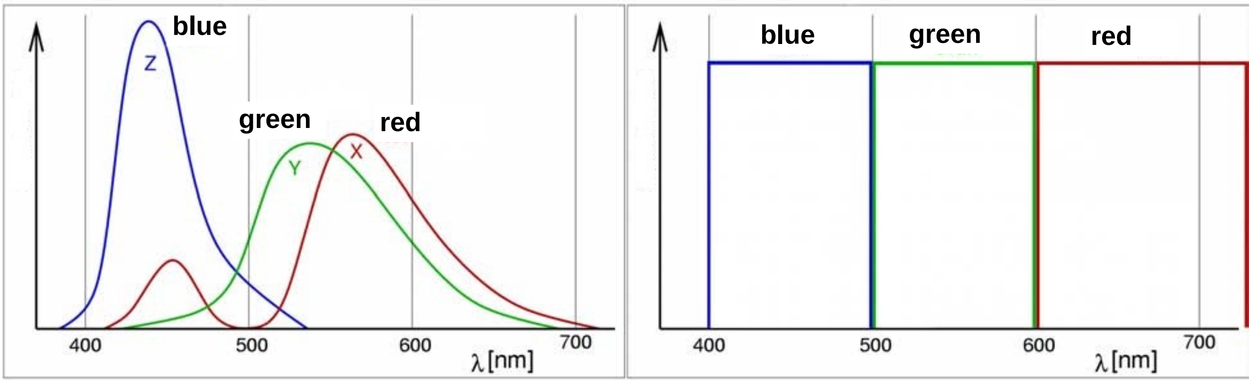



Fig. 6: Left: a ‘true color’ receiver, right: a conventional color receiver.

## stating L*a*b* values is not possible with color sensors

Based on the CIE standard color chart, in the case of color sensors, coordinates for the representation of color and the evaluation are formed from the three signals of the true color receiver (R, G, B). Here as well, as with the formula on page 6, the 1 = X + Y + Z relationship also applies. In turn, an assessment of the color type is possible, but not its brightness. Consequently, an intensity value (INT) is also determined.

Analogous to the L*a*b* color system, there is a further description model available for color sensors. Here, however, in the case of color sensors, it is not always possible to state L*a*b* values. This is because here, neither the required measuring arrangement of the light source/color receivers nor the standard light source with a D65 spectrum is provided.

The coordinates are therefore referred to as s i M values for the color sensors. For displaying the reference and measured values , there are two additional display options (2D and 3D) available.

## 2D representations

In the case of 2D representations, either the X/Y pairs or s/i pairs are calculated in order to evaluate the individual receiver signals for the red, green and blue components. The INT or M intensity values are also calculated. For the X/Y or s/i coordinates, it is possible to specify a permissible deviation tolerance. This also applies to the intensity of INT or M. The color measurement results are visualized graphically in a 'quasi-standard color chart'. Here the stored color reference values are mapped with their respective tolerances (tolerance circle). In addition, the currently measured light intensity of the received signal is shown. (Fig. 7)

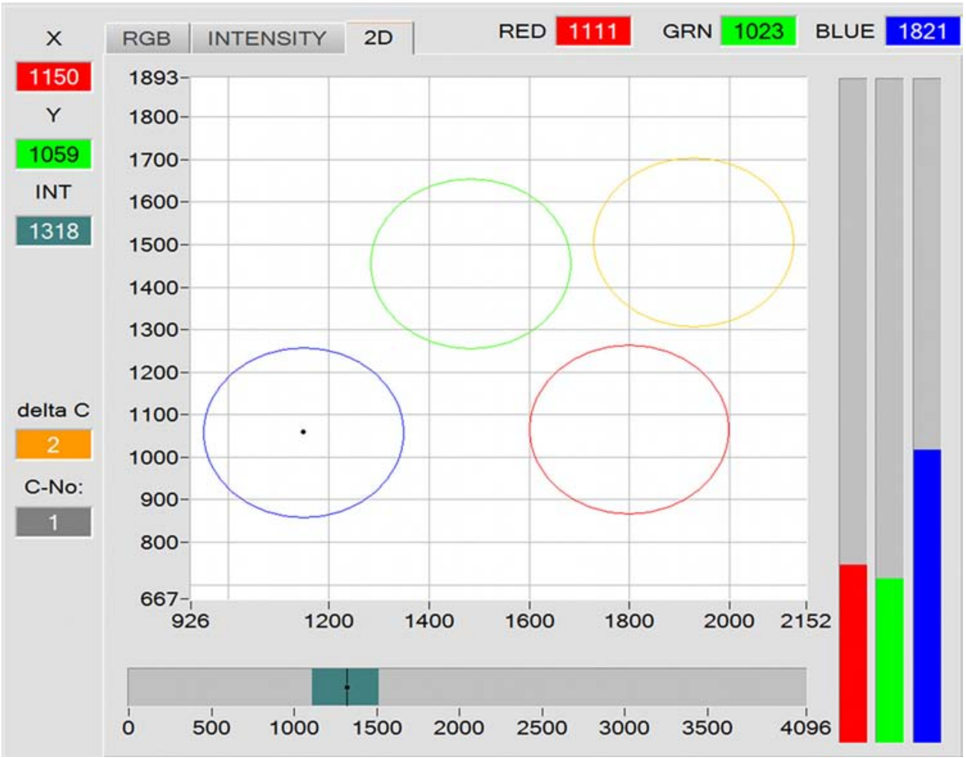



Fig. 7: In the case of 2D representations, either the X/Y pairs or s/i pairs are calculated in order to evaluate the individual receiver signals for the red, green and blue components. The INT or M intensity values are also calculated.

## 3D representations

For 3D representations as well, either the X, Y, and INT or the s, i, and M coordinates are calculated from the individual red, green and blue components. A permissible deviation tolerance is now determined for this coordinate triple. A sphere with the radius ‘TOL’ is practically spanned around the coordinate triplet in three-dimensional space. In order to visualize the tolerance spheres for the stored reference values, a ‘three-sided-view’ is referred to. This is where the X/Y /INT and/or s/ i/M coordinates are displayed that were calculated on the basis of the current receiver signals. The receiver raw data that is currently measured for the red, green and blue components is also displayed. (Fig. 8)

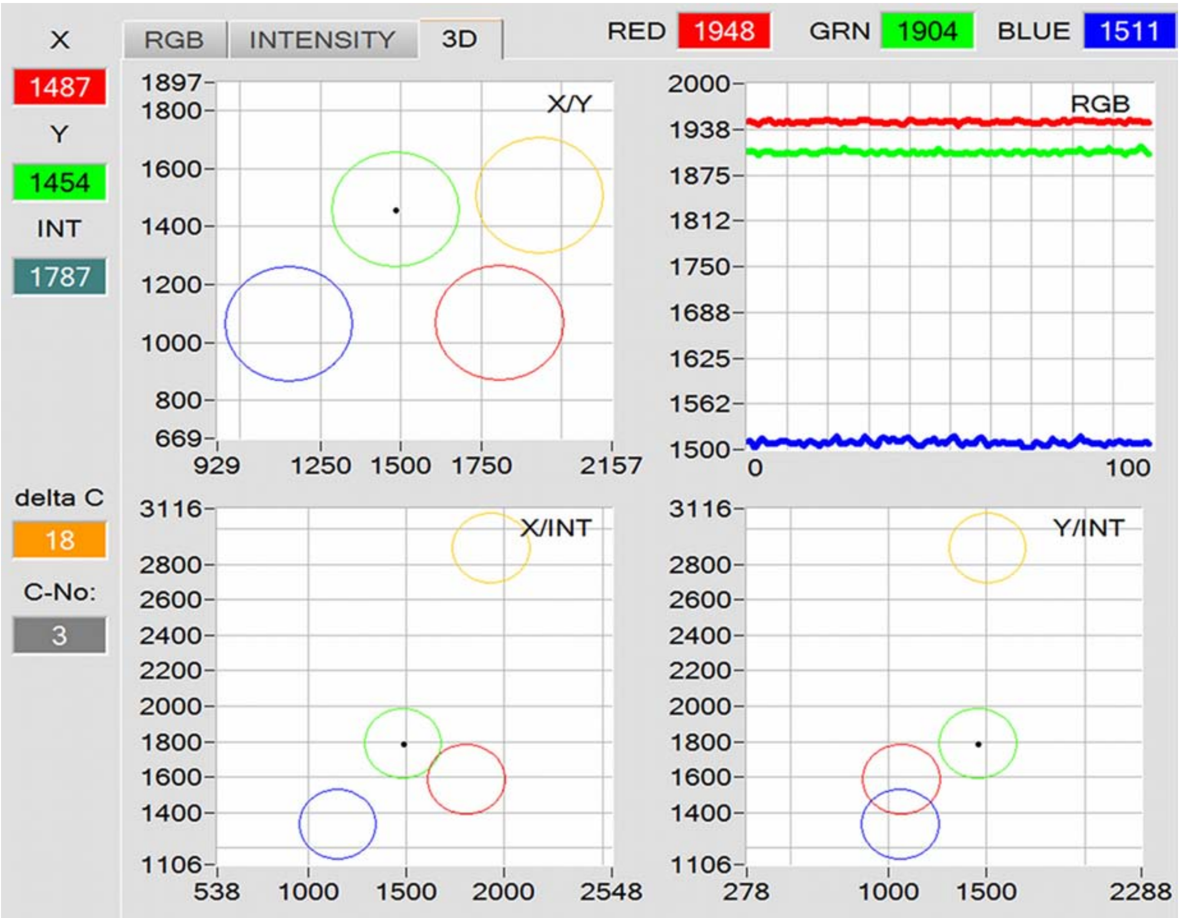



Fig. 8: In the case of the 3D representation, in order to visualize the tolerance spheres for the stored reference values, a ‘three-sided-view’ is referred to. This is where the X/Y /INT and/or s/ i/M coordinates are displayed that were calculated on the basis of the current receiver signals. The receiver raw data that is currently measured for the red, green and blue components is also displayed.

## different models for different tasks

In the case of fluctuating detection intervals and provided that objects can, above all, be distinguished on the basis of color, the s/i /M model is recommended. This is because, due to the calculations, any changes that may occur in the distance between the sensor and the measured object may only have a slight impact on the intensity coordinate M.

However, if the objects to be detected have very similar colors that differ substantially in terms of the brightness and/or intensity of the reflected light, the X/Y /INT model is preferable, because with this model the intensity change has a maximum impact on the INT coordinate. When using this model, care should be taken to ensure that the distance between the sensor and measured object remains as constant as possible.

## also, the evaluation of ‘primary light sources’

Color sensors from ipf electronic can be operated with built-in as well as external light sources and can achieve a maximum switching frequency of 35kHz.

In order to check so-called primary light sources such as LEDs, the taillights of vehicles, halogen lamps and fluorescent lamps for their color and brightness, the internal illumination of the sensors should be switched off.

In addition to the extremely bright white light source, the transmission element is a powerful source of UV light for evaluating fluorescent materials.

## large detection areas

Using different lenses, the color sensors cover working distances ranging from almost 0 to 500 mm in detection ranges of Ø 0.5mm up to Ø 100mm. Through the use of the optical fiber version, color evaluations are possible in hazardous areas or in environments with limited space.

## suitable for every surface

In the detection of shiny surfaces, such as the painted surfaces of car body parts, so-called polarizing filters are used to eliminate the disturbing total reflection of the object surfaces. Focused lenses can be used in order to distinguish between matt and glossy paint surfaces. If, in contrast, the reflection behavior of matt or shiny surfaces is not supposed to have an impact on the measurement result, units with integrated diffuser attachments are available.

## averages cope with difficult surfaces

In the case of difficult surfaces, one special characteristic of ipf electronic color sensors is their ability to determine reference or target values  by averaging one or more good components over several target surface points.

As an alternative to this, it is also possible to logically link several reference and target values for a surface in the system. (Fig. 9)

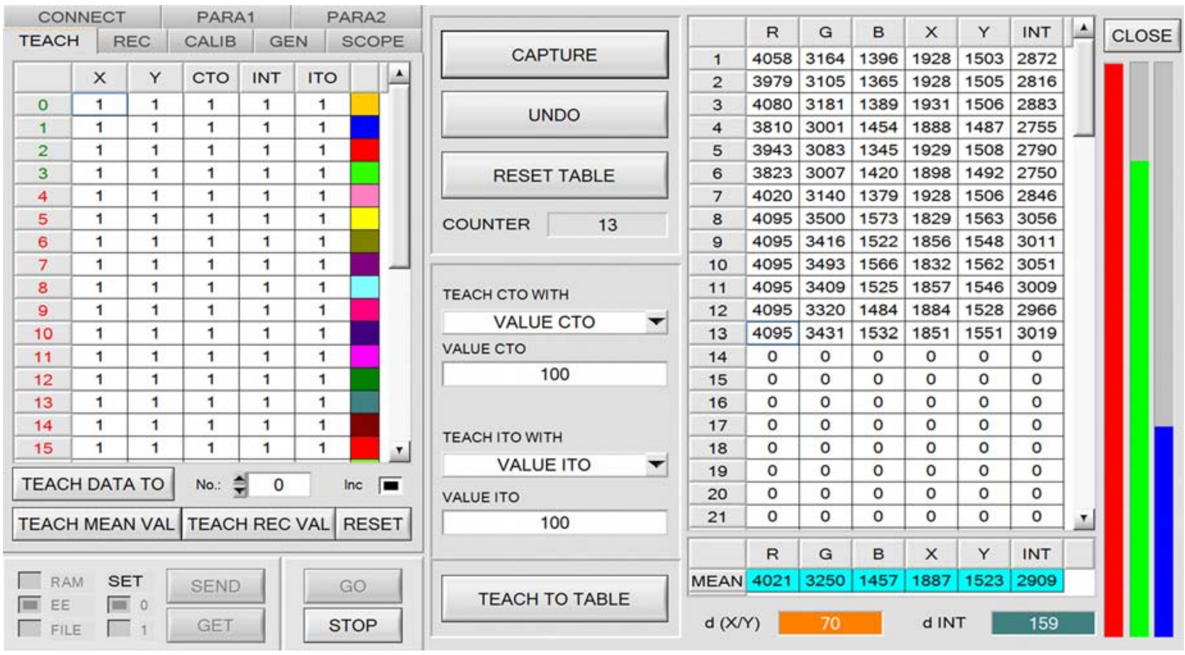



Fig. 9: In the case of difficult surfaces, one special characteristic of ipf electronic color sensors is their ability to determine reference or target values  by averaging one or more good components over several target surface points.

## application examples

There are many applications where the color of objects has to be checked. However, the different properties of the surfaces to be detected (e.g. very inhomogeneous or glossy) often make reliable color evaluation difficult. In the case of color recognition, the ever-evolving ‘true color’ sensors have proven to be real problem solvers. Three examples – glass, metal and painted body parts - illustrate this point.

## 1. type based selection of glass bottles

A company on the river Moselle specializes in the cleaning of wine bottles. After rinsing, the bottles have to be sorted in terms of the color of the glass (brown, clear, blue and three different shades of green). A OF34 series color sensor with glass fiber optics is used, not only to securely differentiate the uniquely identifiable colors, but also the similar shades of green in the different bottles.

## eliminate disturbing light influence sure

The task of detection is made even more difficult by the pressing seams in the glass, various glass thicknesses and, in part, bottles that have been wetted with drops of water. The color sensor that is used operates using a fiber optic sensor through which the bottles are passed.
As a transmitting light source, the device integrates a clocked, very bright, white light LED. This ensures that the impact of ambient light (e.g. hall lighting, etc.) does not affect the test results.

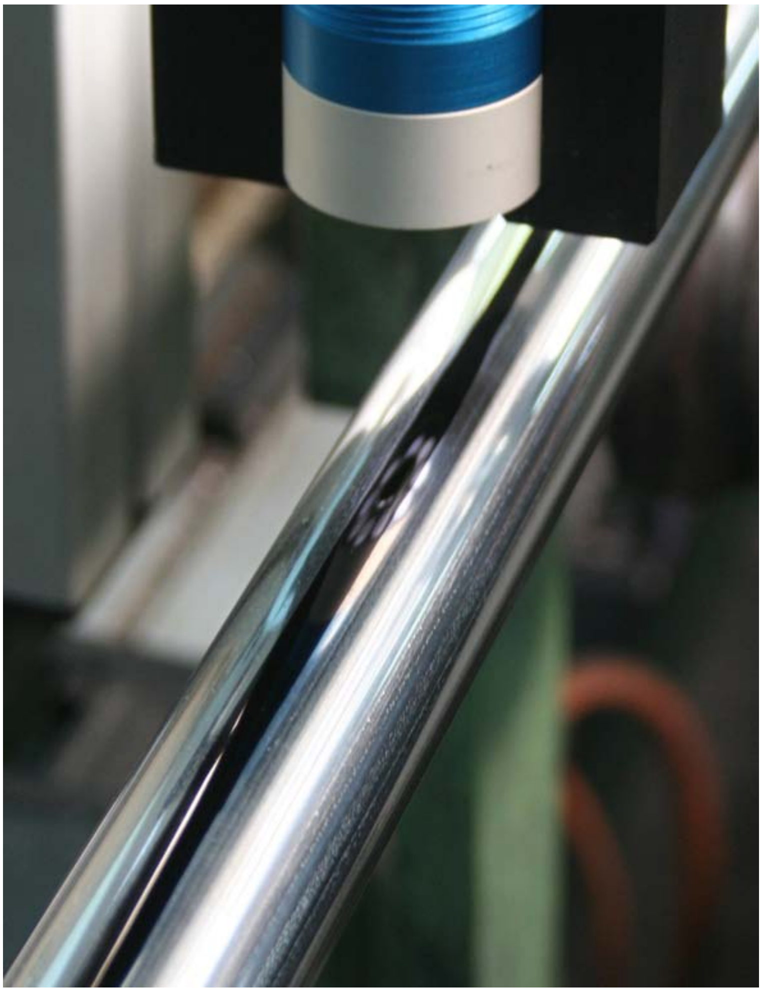
In this case, the sensor system operates completely independently and automatically starts the color evaluation whenever a bottle neck passes by the detection area of the fiber optic sensor.

## more process security through color groups

In this specific application, the sensor evaluates the receiver signals in the so-called 'best -hit' mode. Here, the measured values are jointly compared with the stored reference values/teach values. These are stored with associated parameterization and evaluation software and the 'best hit' is outputted as a result. In order to securely capture all of the possible variations of a type of bottle (with/without press seams, different thicknesses of glass and water residue on the bottle neck) with processing accuracy, it is also necessary to teach the different states of each bottle design as reference values and, using the software, group them together into so-called color groups.

As such, each color group thus represents a selection of different bottle types. Whenever there is a match between the measured value and the reference value of a color group, a same color match is outputted from the sensor. This way, deviations can compensate for a type of bottle and a reliable detection of the glass color can be realized.

## 2. color markings on stainless steel



The qualitative monitoring of a color mark on the weld seams of stainless steel strip tubing represents another application. Here, the material is much more robust but no less difficult than glass.

This marking of different colors according to customer requirements is sometimes necessary if, for example, the tubes have to be bent for various applications. In this case, the weld must be detected and brought into a predetermined position before the shaping process. In order to facilitate the detection of the longitudinal weld seam, the latter is already marked by the manufacturer. It is not only the reflection of the pipe’s shining surface and the freshly applied marking that makes the task of detection difficult, but also the fact that, in addition to the colors that are already used, new ones can be added for markings.

## gloss effects and reflections in the grip

An OF34 series color sensor is also used in this application. The problem that the color shade of the applied marking is ‘brightened’ or ‘softened’ depending on the level of shine on the surface, the direct reflection of the tubing and the colored marking are all factors that are mastered by ‘true color’ sensors through the use of an additional polarizing filter.

As in the first example, the software belonging to the system also ensures that additional application-specific tools can be used for reliable color detection. As such, with the help of software, it is also possible to evaluate the degree of reflection of a surface and establish specific tolerances for the intensity of the reflected light (among other things).

## continuous inspection

In order to monitor the weld seam markings, the sensor is mounted above a roller conveyer at an operating distance of 20mm to the surface being tested. Via the software, the light output of the white light LED and the permitted tolerances for the color/intensity variations are specified . During the production process, the operator simply teaches the sensor the current color of the marking with each color change by pressing a button. As a result, additional and/or new shades do not represent a problem for the marking process. Following this, the sensor continuously checks the paint in the area of the weld. Here, the tubing moves under the unit at a speed of around eight to ten meters per minute.

## 3. automated checking of paint


A leading German automobile manufacturer wanted to realize this application on vehicle bodies over the course of an entire daily production output of around 2,000 cars. Here, it was necessary to ensure secure, highly repeatable color recognition of approx. 17 paint colors (and their gradients) alongside glossy surfaces and, in part, shades which were very similar.

### similar paint colors - a special challenge

For this task, the manufacturer decided on a OF35 series color sensor with integrated polarizing filter which eliminates the glossy effect of the painted vehicle bodies and, in doing so, enables a reliable measurement of the color.

For the parameterization of the color sensor, the software that has already been mentioned is used. Here, however, it was a range of very similar blue paint colors that presented a particular challenge. In order to be able to detect minimal color differences, it is necessary to accurately adjust the light output of the sensor's white light source via the software. In combination with specific evaluation algorithms and the option of specifying graded tolerance values, it is not just the paint colors that can be evaluated with certainty, but also the gradient.

During parameterization, using the software, the transmitting power of the white light source is adjusted for each of the 17 paint colors in such a way that the sensor provides the required measured values.

On the basis of the specific transmission output that is identified using this technique it is then possible, using the software, to establish reference values for the color shade and the intensity of the quantity of light that is reflected from the surface.

## continuous detection in the "First - Hit - mode"

This way, since a statement could be made about the course and/or the accuracy of the shade alongside the ongoing process, a color gradation tolerance was determined for each paint color. Concerning these gradations, it was possible to determine corresponding parameter sets that were stored under a reference number on a host computer.

For an exact identification of the paint shades, the current measured values of the color sensor are compared to the reference values that are determined in advance for the color parameters / intensity parameters for a paint shade-specific basic output of the light source, and the corresponding tolerance graduation. The sensor only specifies color errors when an incorrect color shade or too much of a shade gradient is detected.

The receiver signals are evaluated by the sensor in the so-called ‘first-hit’ mode. Here, an internal comparison of the measured values takes place with the reference/teach values stored in the sensor, and the ‘first hit’ is outputted as a result.

## communication between host computer and sensor

The host computer on which the reference data and/or reference values are stored for each type of paint is connected with the sensor via an RS232/Ethernet converter and/or a gateway. The vehicle body to be examined is identified by a barcode reader on the side of the system. This way, the host computer recognizes which paint should be applied to the body. In order to confirm this information by the sensor as well, the host computer transmits the necessary parameter sets to the color sensor. This sensor compares the test parameters with the measured values and indicates whether the values are within the color, gradient and intensity limits. In turn, the test results are passed to the host computer in order to ensure the production data.