White Paper

MICRO-EPSILON

Learn how color sensors open up perspectives for automation and machine building

Determination, measurement and detection of colors in industrial applications are complex measurement tasks. Compared to other physical quantities, it is difficult to define color: what exactly is color? State-of-the-art color measurement technology does not only answer this question but also offers solutions for industrial applications.

What is color?

Color is individual, visual sensation elicited by light. Color impression is subjective and depends on age, sex and daily mood, while factors such as illumination, background and surface structure also play an important role.

A human has no "color scale". Our brain creates an individual color impression making impossible adequate color description and documentation. Perceived colors are produced by receptors on the retina. Approx. 6 million cones are responsible for color perception and approx. 120 million rods for light/dark differentiation. Color inspection in industrial applications requires sensor technology that corresponds to the color perception of the human eye. The latter is invoked by light in the wavelength range of 380nm to 780nm.

Human color perception vs color spaces

Based on human color impression, colors can be described differently. Since 1931, the CIE 1931 standard color space stipulated by an international commission has ensured comparability in color descriptions. At the same time, parameters such as observation conditions and illumination were stipulated in order to ensure comparability of the color measurements.

There are numerous color spaces for different purposes. In technical applications, the CIELAB color space is more common. It is generated from the standard color space by transformation. The coordinates of this color space are L as measure of the brightness, a (green/red saturation) and b (blue/yellow saturation). The advantage of this color space is that each hue perceived as a separate color by the human eye has the same volume. The HSV/HSI color spaces are rarely used. The RGB and CMYK color spaces used with monitors and printing technology are significantly smaller than the CIE standard color space. This means they cannot image all colors that the human eye recognizes and so are not suitable for precise, industrial color measurement.

In addition to the color spaces, other definitions are important. Therefore, regulations regarding lighting and observations distance were stipulated by the CIE commission. Another important parameter for industrial applications is the so-called color distance Delta-E which is the distance between two colors in the color space. Depending on the color, the human perception is limited at 0.5 to 1. The automotive industry requires Delta-E < 0.1.

Why measuring color in industrial processes?

In many industries, color implies quality. Particularly with consumer goods that arrive at the final customer, the exact color shade affects the value and identity of the product and the brand. Therefore, it is crucial to match the correct color shade in the production process and to produce it homogeneously throughout numerous batches.

Color not only leaves behind a quality impression but can also be used as indirect quantity to control the process. For example, color sensors are used to monitor the presence of adhesive beading, to sort parts or to determine active ingredients. Color sensors are in most cases the more cost-effective solution as they provide more precision than conventional switching sensors do.

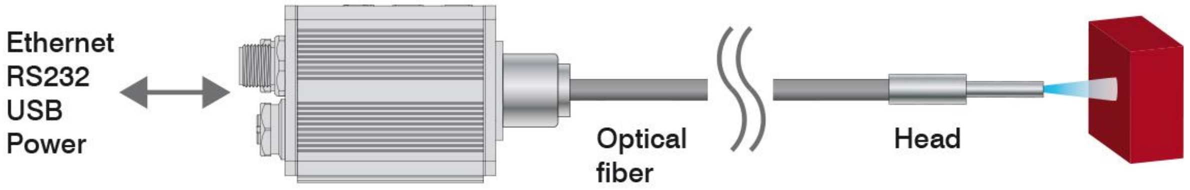
Various sensor types to precisely detect and measure colors

Color is (in physical terms) a reflected intensity spectrum in the visible wavelength range. This reflection spectrum depends on the object color and the illumination. Illumination is defined by different light sources, e.g. light bulbs, daylight, fluorescent lamps or cold white LEDs. A color sensor detects the reflected spectrum and imitates the principle of the human eye. Therefore, the reflected light is refracted into its spectral parts. The easiest method is to use filters where only one part of the spectrum can pass through. The following products have proven their worth in precise color recognition and measurement.

True Color Sensors for precise color recognition

True Color sensors such as the colorSENSORs from Micro-Epsilon are based on an accurate color recognition principle. The specimen is illuminated by a light source, which in most cases is a white light LED, via fiber optics. The light reflected by the sample is transmitted via fiber optics to the controller where the light passes through three different filters and eventually reaches a light-sensitive sensor element. The filters divide the light into long-wave (X), medium-wave (Y) and short-wave (Z) parts. The individual signals are then transformed into L*a*b* color values. This is how measurement values are generated which enables the assignment of colors according to the color perception of the human eye. Therefore, we refer to these as perceptive color sensors or True Color sensors. They are ideally suitable to recognize deviations from a reference color. A teach-in function enables the user to program the desired color on the sensor and to define the maximum permissible color deviation. The sensor rapidly compares the color of the products during operation and sends for example a signal via a digital output if the color of the specimen is within the tolerance limits.

So-termed color groups imply another useful feature. The user can teach several color distances to the controller and group them. If the distance from the target changes and therefore also the recognized color, the latter may be contained in one of those groups and so is in the defined tolerance range.



True Color CFO sensors comprise a controller and a sensor head with fiber optics. This design makes it possible to reach difficult-to-access places. High temperatures and mechanical stress are no match for these color sensors.

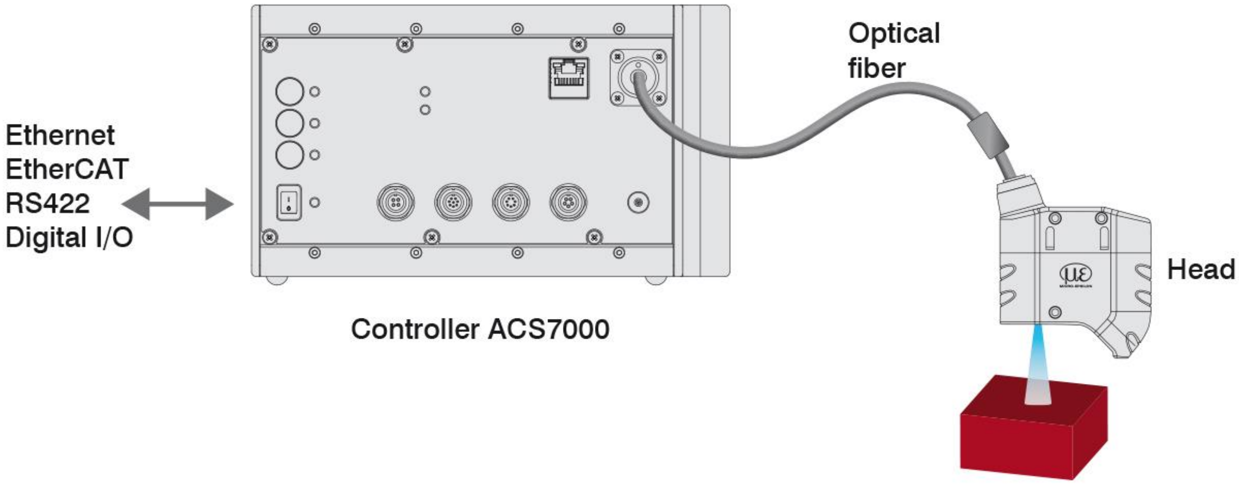
Color spectrometer for high precision color measurement

Another functional principle is applied by color measuring systems such as the colorCONTROL ACS7000 from Micro-Epsilon. This divides the spectrum of the incident light via a refraction on a grid into 256 parts, which are imaged behind the grid onto a CCD sensor line. This is how the complete visible spectrum can be accurately measured with a spectral resolution of 5nm. The color measuring system not only compares the colors to reference values, but also identifies and outputs individual colors as coordinates in the color space. As well as the sensor system, the white light LED is incorporated into the controller, enabling different sensor heads to be connected via optical-fiber cables.

In the ACS1 standard sensor for conventional measurement tasks, illumination and receiver are either arranged at an angle of 30°x:0° or 45°x:0°. This leads to observation distances of 50mm or 38mm respectively.

For more complex measurement tasks e.g. with structured, highly reflective or shiny metallic surfaces, the ACS2 circular sensor with 24 circular arranged lighting optics at a measuring angle of 45°c:0° is used. This ensures continuous, homogeneous lighting for measurements, regardless of the angular position of the target object. Even with smaller measurement objects or on curved surfaces, reliable color measurements are possible.

For color measurements of transparent objects such as film or glass, the ACS3 transmission sensor is required where illumination and receiver are arranged at an angle of 180°:0° to each other. This receiver sensor also measures colors of self-luminous objects. No lighting unit is required



Color spectrometers from Micro-Epsilon enable true color measurement. The system comprises a controller, an optical-fiber cable and different sensor heads which can be used for shiny, curved and transparent surfaces.

Application examples

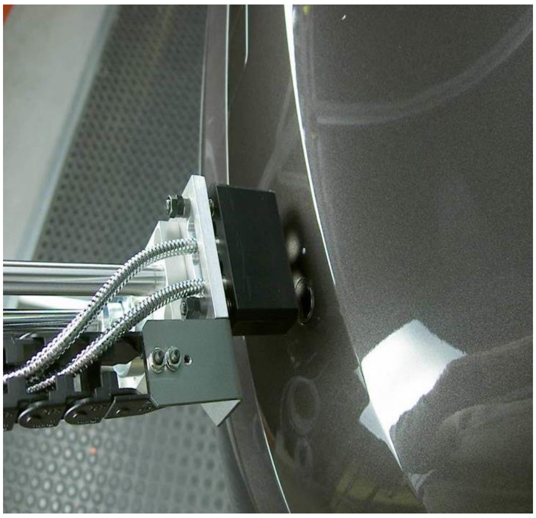
Measuring the zinc strip color in production

In the production of high-quality material strips and boards made out of titanium zinc, the surfaces receive specific treatment. So the strip receives defined coloring. For color inspection, ACS7000 color spectrometers from Micro-Epsilon are used to monitor the color shade in the running production line with high speed and high accuracy.

Color recognition for seams in automotive interiors

In the assembly line of a car manufacturer, car interior parts are distinguished on the basis of different seam colors. Micro-Epsilon color sensors automate this process. Due to their high measurement resolution (color distance ΔE = 0.5), these True Color Sensors easily distinguish color shades that look virtually the same to the human eye.

Comparing colors of parking sensor and car body



Car attachments such as parking sensors are painted separately. In the assembly, the color of the parking sensors must match the car body color, i.e. the color difference must be equal to zero. The True Color sensors from Micro-Epsilon enable a direct color comparison between the parking sensor and the rear bumper. The sensor issues a ‘NOK’ signal if the colors differ and an ‘OK’ signal if the colors are identical. The colors don’t have to be taught to the sensor. The user simply needs to define the maximum color difference between the two color channels.

Inline detection of protective film on PVC window frames

After their extrusion, a protective film is applied onto the PVC frame profiles. This film protects the frames from scratches and dirt. Applying the transparent protective film changes the color of the window frame slightly (color change of $\Delta E = 0.1$). The colorCONTROL ACS7000 color measuring system checks if the protective film has been applied, and whether it is applied correctly.

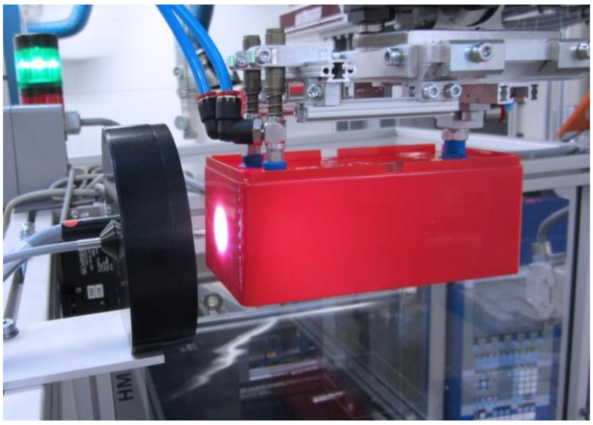
Color measurement of tablets in pharmaceutical production

In vitamin tablet production, different ingredients are used. The tablet color depends on the concentration of ingredients and might vary from pure white through to beige and yellow. The colorCONTROL ACS7000 inline color measuring system with a 30° sensor head accurately measures the slightest color differences, particularly those finely-graded color shades between white and beige. This color information provides a statement about the quality of the ingredient composition.

Color detection of furniture and kitchen fronts

Kitchens are available in many different colors. In order to ensure homogeneous color application throughout several production batches, the colorSENSOR inspects the color of kitchen fronts in the painting plant to recognize slightest color deviations which are imperceptible to the human eye. The inspection also covers color fluctuations which might occur in the course of time.

Inline color measurement of injection-molded plastic parts

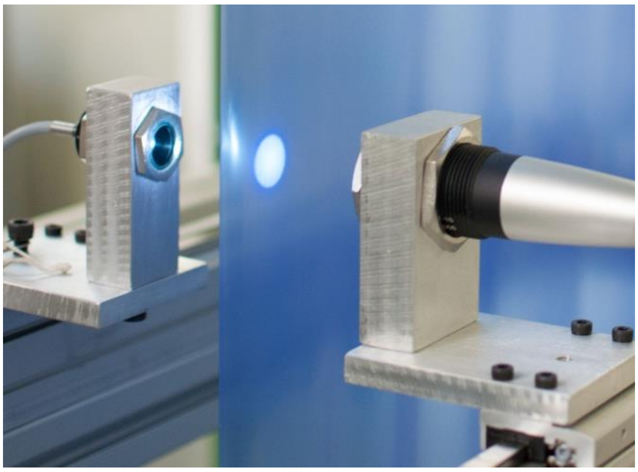


In plastic injection molding, the exact color shade of the products is important. As the color changes during cooling, it was only possible to determine the color via random checks of cooled parts. The colorCONTROL ACS color measuring system inspects the products as they are extracted from the mold. The system uses an empirically determined correlation of the color between warm and cold pieces. This enables any color deviations to be recognized at an early stage thus avoiding waste.

Color and intensity tests of vehicle lights

After the assembly process, vehicle lights are tested in terms of color and intensity. Homogenous distribution of light should also be ensured with fluctuating LED batches. The LED colorCONTROL MFA Analyzer performs this color inspection. Fiber optics enable to measure the lights at different points simultaneously, which ensures that every single LED is tested. With the colorCONTROL MFA-5, between 5 and 20 measuring points can be tested at the same time.

Inline color measurement of transparent films

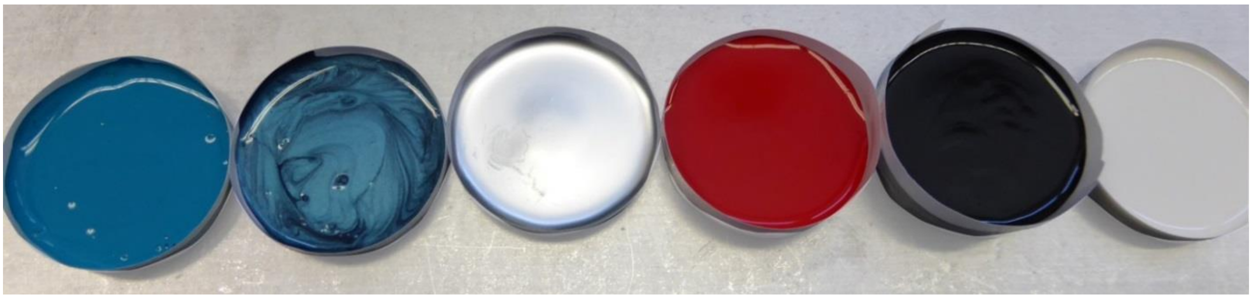


As well as color fluctuations, streaks can occur during production. The color homogeneity of transparent film strips is monitored inline without making contact. As transparent films are translucent, the color is measured in transmission, i.e. that a transmitter illuminates the receiver and the film in between. This is possible with the high speed, high precision colorCONTROL ACS7000 inline color measuring system, which is connected to a transmission sensor head (ACS3) comprising a transmitter unit (tt) and a receiver unit (TR). This system enables the early detection of any slight changes in color and streaks, allowing production parameters to be modified accordingly.

Color measurement of liquid paint

Measuring the color of liquid paint is extremely challenging. To date, paints have been typically applied on a test area first and then tested only after the drying process. If the colors deviate, the paint containers must be mixed again or even disposed of which partly involves long waiting times.

In order to accelerate this process, Micro-Epsilon has developed a system that enables the measurement of liquid paint. In color measurement technology, the spectral distribution of the reflected light depends on the distance. Therefore, even changing distances larger than 0.05mm will influence the measurement results. However, the height tolerance with which paints can be filled into the sample container is limited to ±2mm, which means distance measurements and controls are required to achieve high precision and reproducible measurement results. This application therefore includes the colorCONTROL ACS7000 color spectrometer for color measurements and the optoNCDT 1420-50 laser distance sensor. A linear unit offers automatic readjustments. This ensures the correct distance between the color sensor and target.



Marking detection on cosmetics bottles

Color sensors from Micro-Epsilon are not just used for color measurements but also in detection, testing or positioning tasks. When automatically printing on semi-transparent glass ceramic bottles, it is necessary to determine the exact position for the printing. Before the printing process, a position mark is embossed into the bottles. The color of the embossment deviates slightly from the rest of the bottle surface. The colorSENSOR CFO100 detects this color difference, which enables the exact determination of the printing position. If the marking is missing, the bottle is considered as faulty and will be rejected immediately. Thanks to its high speed measurement frequency, the True Color sensor outputs a complete OK / NOK signal within the specified cycle time of less than two seconds. Its small measurement spot size with a diameter of just 0.6 mm ensures reliable and precise embossment detection.

Basics of color measurement

Color assessment based on:

- Hue: Color differentiation e.g. red, green, blue, yellow, etc.
- Brightness: Intensity of light perception, color appears darker or brighter
- Colorfulness: Intensity of the color compared with a gray color (not colored) with the same brightness
- Saturation: describes the relation between colorfulness and brightness

Spectrum

We perceive color stimulus between 380 nm violet and 780 nm red and can distinguish up to 10 million color shades.

Color spaces

The human eye has three color receptors (L = long, M = middle, S = short). This is why 3D color models are used in order to clearly identify colors and to compare these with other colors (see color distance). In the industry, particularly the L*a*b* color space has become established.

Standard color space CIELAB76

The L*a*b color space comprises all colors perceptible to the human eye. In this 3D color model, each hue is described with approximately the same volume of space. The L*a*b* color space has established itself in the industry and is used by device manufactures for color inspection.

Each color is described by the color location (L*; a*; b*).

- L* = lightness (black = 0; white = 100)
- a* = green/red colors (green = -100; red = +100)
- b* = blue/yellow colors (blue = -100; yellow = +100)

Color distance ΔE

The larger the difference between the colors within the color space, the more clearly the difference can be perceived with the human eye. This is defined as ΔE color distance.

Delta E; ΔE; dE = is a metric for the perceived color distance between colors (DIN 5033)

Interpretation:

- ΔE > 5 Large color difference
- ΔE 0.5 … 1 Limits of human perception
- ΔE < 0.3 Required by the paper industry
- ΔE < 0.1 Required by the automotive industry

Standard illuminants and light sources

- Standard illuminants are defined from 380 to 780 nm.
- Illuminant A = light bulb with 2865 k
- Illuminant D65 = medium daylight with approx. 6500 k
- Illuminant F11 = fluorescent lamp
- Cold white LED

Please note with precise color measurements:

- The sample surface must be as clean as possible. Finger prints, scratches, dust and residues of cleaning agents distort the measured results.
- Curved surfaces: always measure at the same location on the target with the least amount of curvature to achieve a reproducible result.
- Make sure that the sample is optimally positioned. If the distance from the sample changes slightly the measurement results will be influenced. The color distance might vary slightly due to tolerance ranges or color groups.
- Constant surface temperature is important for comparable results as different temperatures can lead to deviations. Samples in best quality should be qualified as representative master.
- Regular calibration is a prerequisite for reproducible results and should be performed under the same ambient conditions prevailing during the subsequent measurement.
- The object to be measured shall be larger than the measurement spot.

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