EN

WHITE PAPER

CAMERA SENSOR TECHNOLOGY PART 3

ALL A QUESTION OF LIGHT

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IPF ELECTRONIC

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1 INTRODUCTION

The range of potential uses for camera sensors is extremely broad, whereby the basic objective in every application is to examine specific features on certain objects. For this task to be performed successfully, the image processing system of the camera sensor must, in the context of reliable evaluation, obtain an image suitable for object inspection in order to, e.g., be able to clearly highlight or recognize specific object features or inspection characteristics, respectively. Such recognition is, however, only possible with a high-contrast image that clearly highlights such features. When using camera sensors, the illumination thereby plays a decisive role, as it significantly influences the test results in an application, especially if the features to be inspected on an object vary from component to component. With respect to a specific application with a camera sensor, it is estimated that proper illumination accounts for two thirds of the success of an application solution.

It must be emphasized in this context that there is no “standard recipe” for selecting the proper illumination for a given application. Much more important are, rather, the various experiences one has made from implementing solutions for different fields of use. Fundamental knowledge of the influences of different types of illumination on the feature check of objects is extremely helpful here. The third part of this series of white papers on camera sensors focuses intensively on this topic for this reason.

2 SOME TERMS AND HOW THEY’RE USED

The topic of “illumination” is extremely complex. It therefore makes sense to get started by explaining the meaning of a number of specific terms and how they relate to one another. In this white paper, a distinction is generally made between illumination type, illumination direction and illumination technique. The relevant terms in this context are:

Illumination type

- Incident light
- Transmitted light

Illumination direction

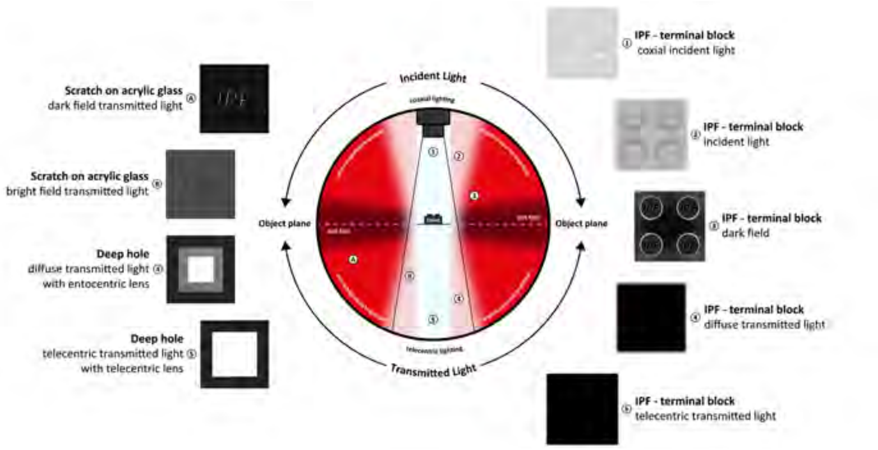
- Bright field, partial bright field, dark field

Illumination techniques

(the individual illumination techniques are explained in further detail in Chapter 5)

3 ILLUMINATION TYPE

With respect to the illumination type, a distinction is generally made between an incident illumination type and a transmitted illumination type. With incident light, the illumination is located above the object plane. With transmitted light, however, the light source is implemented as background lighting and is located below the object plane.



Position of the illumination and a number of effects on the feature check of objects.
(All images: ipf electronic gmbh)

4 ILLUMINATION DIRECTION

With both incident light as well as transmitted light, one can differentiate between various illumination directions. To a certain extent, the illumination direction describes the angle of incidence of the light beams on an object or an object surface. Depending on the illumination angle, a bright field, a partial bright field or a dark field is produced.

4.1 BRIGHT FIELD, PARTIAL BRIGHT FIELD AND DARK FIELD

In a bright field, the beams of a light source with incident light are reflected by an object surface and projected directly onto the camera optics. With transmitted light, the bright field is created by directing the light beams from below directly through a transparent object or, e.g., through a bore in the object to the camera optics. Strictly speaking, a 100% bright field can, however, only be produced using a telecentric illumination technique (see Chapter 5). In the context of the illumination direction, it is therefore necessary to also include a "partial bright field," as it is possible, for example, when using incident light with a direct or diffuse coaxial illumination technique, for a partial bright field to be formed at the edge areas of an object and a bright field to be formed near the middle of the object if a test object is located directly below the camera optics.

Illumination types that produce a dark field work with both incident light as well as with transmitted light with a type of sidelight. To a certain extent, the light of a light source positioned to the side of the object surface shines across the object surface. Unevenness on a test object or even engravings or surface defects may, e.g., with incident light, deflect a majority of the light beams impinging from the side towards the camera optics so that such features are clearly highlighted in a high-contrast image as bright areas. The remaining object surface is instead depicted darker in the camera image as it reflects none or nearly none of the light beams towards the camera optics.

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5 ILLUMINATION TECHNIQUES

With respect to the illumination techniques, there are a number of different solutions for incident light and transmitted light. It is precisely this fact that makes the camera sensor system (aside from the camera sensor itself, the possible choice of lens and the high-performance configuration software for these devices) so versatile in use, but also problematic – which becomes an issue when it comes to the development of an optimum solution for a specific application. In the following, the various techniques for incident light and transmitted light illumination are presented.

5.1 INCIDENT LIGHT ILLUMINATION

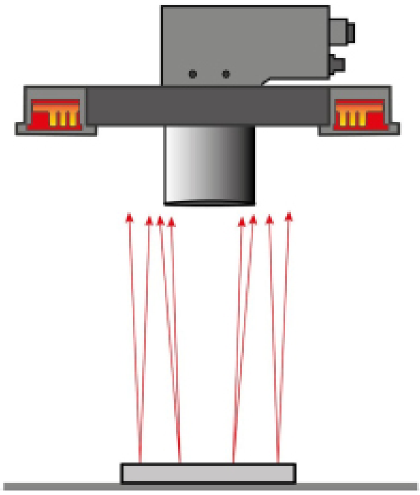
With incident light, a distinction is made between the following illumination techniques:

- direct coaxial illumination
- diffuse coaxial illumination
- telecentric illumination
- bright-field/partial bright-field illumination
- dark field illumination

The term “coaxial” describes the situation in which the light is emitted along the same axis as the camera optics. Thus, the light source is thereby arranged around the lens of the camera, e.g., in the shape of a ring illumination.

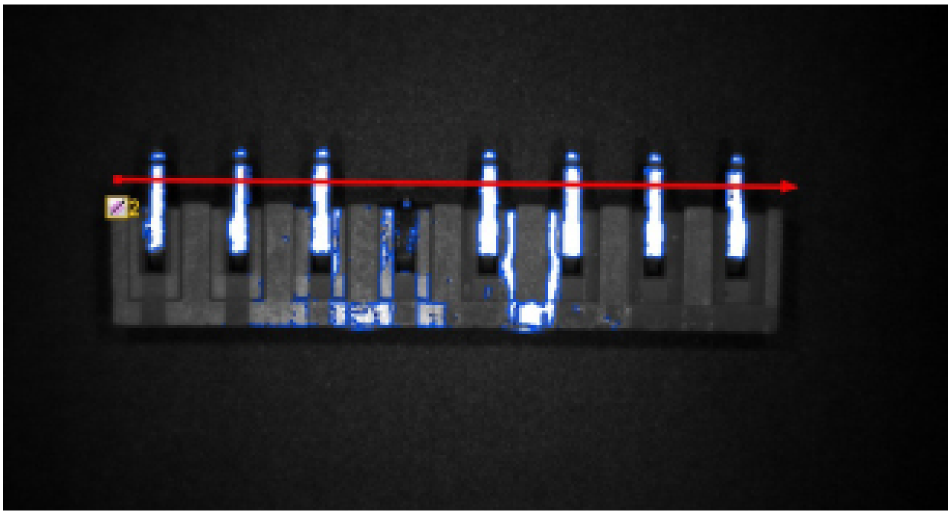
5.1.1 DIRECT COAXIAL ILLUMINATION

With direct coaxial illumination, the light is projected parallel to the axis of the camera optics onto an object. Because LEDs or arrays of LEDs are used today as the light source nearly without exception, the illumination techniques used, for example, with incident light, integrate a diffusor, a diffusion disk or a matt cover in front of the light source (e.g., ring illumination) to achieve a preferably homogeneous light distribution on a test surface. The emitted light is incident directly on the object plane.



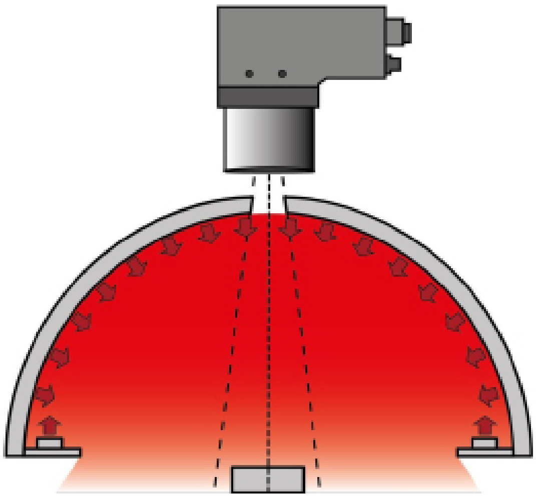
Direct coaxial illumination.

Direct coaxial illumination with incident light is especially well suited for test objects with a flat or smooth, reflective or glossy surface. Examples of this are washers (e.g., for checking the object diameter) or electronic components on which, e.g., the completeness of the contacts is to be checked.



Completeness check of contacts on an electronic component with direct coaxial incident light illumination.

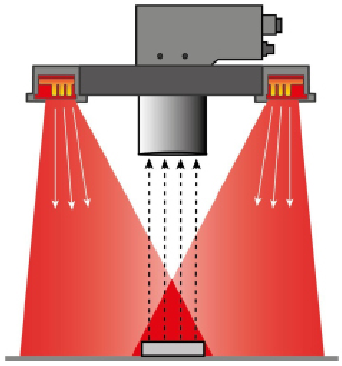
So-called dome illumination, which enables extremely uniform illumination of a test object, is suitable for more complex, reflective objects, such as films, crown caps on bottles or data media (Blu-ray, CDs, DVDs). Because the camera optics positioned over the dome for imaging the object plane with the test object require an opening, a dark area is usually visible on the camera image in the center of the object from which the light of the illumination is not reflected. To avoid this effect, especially high-quality dome lights integrate, among other things, a light source installed to the side of the camera optics that directs the light via a beam splitter towards the object plane.



Dome illumination with coaxial light source.

5.1.2 DIFFUSE COAXIAL ILLUMINATION

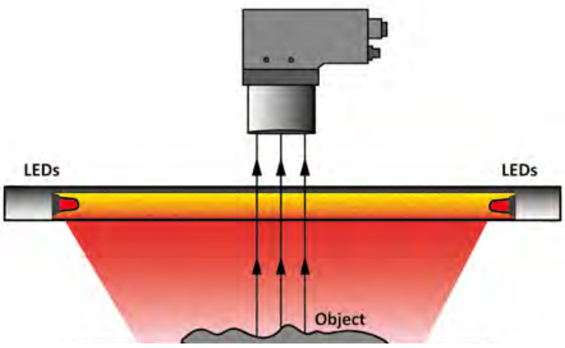
Diffuse coaxial illumination can also be realized, e.g., by means of an appropriate diffuse cover on a ring light. The emitted light is radiated undirected or heavily scattered onto the object plane.



Diffuse coaxial illumination.

With this illumination technique, a diffuse and, thus, very homogeneous light is produced that is ideal for reflective objects with uneven surface. Here is an example: If, when inspecting a shiny pipe, a direct incident light is selected, the vertex of the object (area near the pipe center) reflects the most light towards the camera optics. The edge areas of the pipe, on the other hand, appear as dark zones on the camera image since they reflect very little light back to the detection range of the camera optics. Under certain circumstances, this can have a negative effect on the test results since, e.g., the transition from the pipe edge to the background is no longer high-contrast and, thus, easy to identify. Diffuse coaxial illumination, on the other hand, achieves better light distribution on the entire object, thereby also allowing the edge areas of the pipe to be more clearly identified. Prerequisite for this, however, is that the illumination be significantly larger than the test object. As an alternative, a special illumination design can be used which is slightly bent, similar to a tunnel.

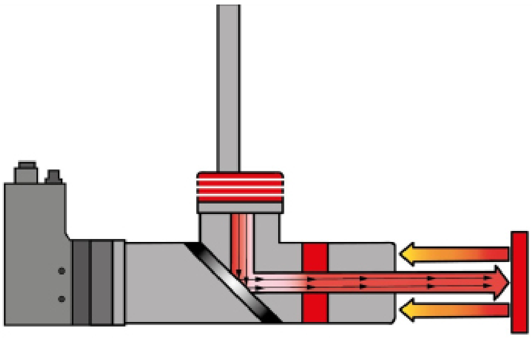
A special type of diffuse illumination is the so-called flat dome. It supplies an undirected light that is distributed extremely uniformly on an object surface. Especially objects with glossy, uneven surfaces that also vary in orientation during the check can be inspected very well with this illumination technique. One disadvantage, however, is that this illumination solution must be applied very close to an object in order to obtain image results that can be evaluated.



Flat dome illumination enables an extremely uniform light distribution over a glossy, uneven object surface.

5.1.3 TELECENTRIC ILLUMINATION

With this illumination technique, the light beams have no angle of beam spread, unlike a direct or diffuse coaxial illumination (cf. figures 2, 4, and 5). Instead, the light beams are incident on a test object through the use of, e.g., special directing optics that are parallel to the camera optics.



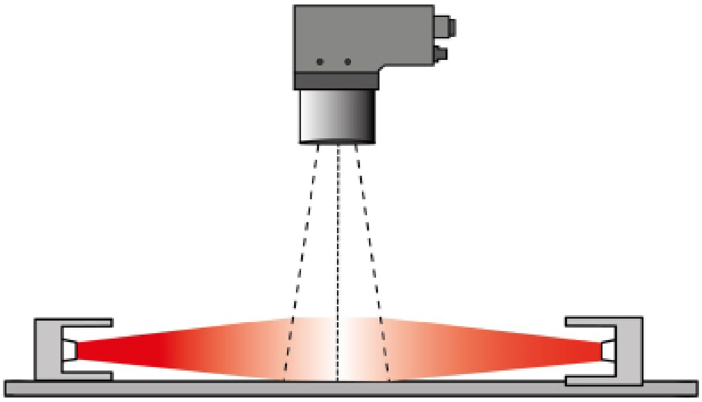
Telecentric/collimated illumination. The beams of the light source are bundled via directing optics and are incident parallel to the camera optics on a test object.

5.1.4 BRIGHT-FIELD/PARTIAL BRIGHT-FIELD ILLUMINATION

The illumination techniques for incident light described thus far can be referred to as bright-field illumination or as partial bright-field illumination, since they are essentially used to evaluate the direct reflection of the light beams from a test object with respect to an object surface. As already pointed out in Chapter 4.1, only the telecentric illumination technique actually produces a “true” bright field, as here the light beams are reflected mainly by the object surface towards the camera optics. With this technique, the reflected light quantity is heavily dependent on the surface structure, i.e., high-contrast images of the surface structure are produced.

5.1.5 DARK-FIELD ILLUMINATION

Dark-field illumination is usually positioned very close to the test object and consists of, e.g., flat ring lights, line lights or spot lights. This type of illumination is frequently used for detecting flaws on object surfaces (e.g. scratches or scoring) or when inspecting engravings. With dark-field illumination, the light reflected by a test object is largely directed to areas outside of the camera optics. Only the reflections of the light beams from object unevenness are detected by the camera optics, whereby errors, defects or specific object features can easily be identified as bright areas.



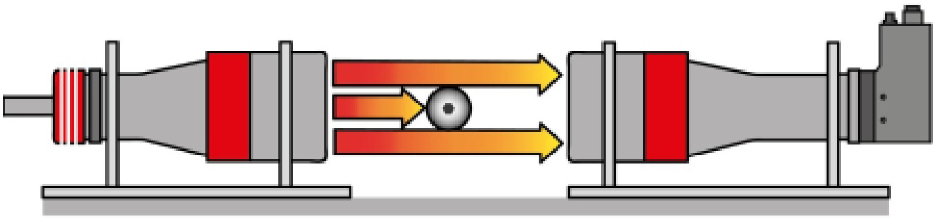
Dark-field illumination is usually positioned very close to the test object and consists of, e.g., flat ring lights, line lights or spot lights.

Picture of a terminal block with dark-field illumination (left). For comparison, the terminal block with bright-field illumination (right). With dark-field illumination, the lettering on the terminal block stands out from the background with high contrast.

5.2 TRANSMITTED LIGHT ILLUMINATION
With transmitted light or background illumination, a distinction is made between the following illumination techniques:

- telecentric illumination
- bright-field transmitted light illumination (diffuse or direct transmitted light illumination)
- dark-field transmitted light illumination
- transmissive illumination

5.2.1 TELECENTRIC ILLUMINATION
Telecentric illumination techniques with transmitted light provide an exact depiction of the test objects, largely free of diffraction effects, and are therefore used primarily for exact measurement tasks.



Telecentric transmitted light illumination for high-contrast lighting without any interfering scattered light in combination with a telecentric lens.

If, on the other hand, an object is illuminated with standard transmitted light illumination, the silhouette or the silhouette of the test object changes with increasing distance between the illumination and the object (left). Due to the deflection or diffraction of the light beams on the object edge, the silhouette is no longer clearly defined. This effect becomes weaker the more telecentric the light is (collimated beam bundle). For precise measurement tasks, a telecentric illumination technique in combination with a telecentric camera lens (right) is therefore recommended, especially with transmitted light that provides good contrast between object and background.

Deep hole. Diffuse transmitted light (entocentric lens) (left). Telecentric transmitted light (telecentric lens) (right).

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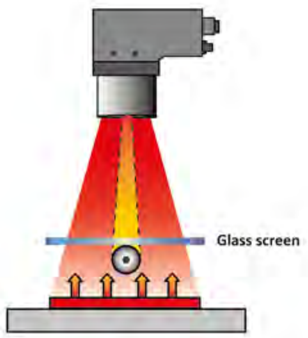
5.2.2 BRIGHT-FIELD TRANSMITTED LIGHT ILLUMINATION

With bright-field transmitted light illumination, a test object is lit from below or behind so that the beams from the light source are directed toward the camera lens. This generates a kind of silhouette of the test object, whereby the object background is visible as a bright area in the image detected by the camera sensor. This illumination technique is mostly used if, e.g., the presence of features (such as punch holes or drill holes) on objects is to be checked in cases where dimensional information is not of primary importance for the test result. Depending on the requirements for the inspection task, light sources with either diffuse or direct illumination are used for bright-field transmitted light illumination.



Example for diffuse transmitted light illumination that generates a kind of silhouette of the object feature that is to be checked. Here, the illumination consists of a flat light source positioned very near to the test object.

A classic use for bright-field transmitted light illumination is, e.g., the inspection of plastic syringe parts. In this context, the shadow of the test object in the camera image is used to check whether the parts have been manufactured without defect or if, e.g., certain product areas are missing or exhibit changes compared to the desired shape because they were not correctly injected in the injection tool. In such a case, part inspection provides information about a faultless injection process, especially at the start of a production process, whereby factors such as the temperature of the plastic, the mold temperature and the injection temperature, etc., play a decisive role.

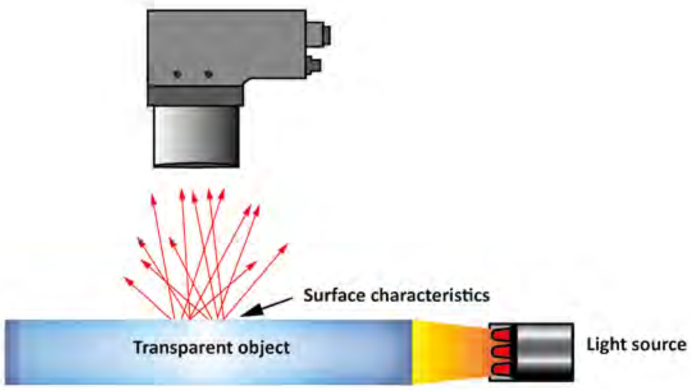
5.2.3 DARK-FIELD TRANSMITTED LIGHT ILLUMINATION

With this illumination technique, specific surface features of transparent objects, for example, can be highlighted very well. Scratches on a Plexiglas pane are an example of this. With dark-field transmitted light illumination, the scratches on the object surface appear in the camera image as bright, clearly identifiable areas that can be clearly discerned from the rest of the Plexiglas pane, which is visualized as a dark area in the image output by the camera.

Scratches on acrylic glass. Left: With dark-field transmitted light illumination, the artifacts stand out as bright areas. Right: Bright-field transmitted light illumination.

5.2.4 TRANSMISSIVE ILLUMINATION

This illumination technique is a special type of dark-field transmitted light illumination because the light is quasi-injected sideways into a transparent object. The test object thus functions to a certain extent as a light guide through which the light can pass. Defects such as cracks, scoring, scratches as well as deformations can be clearly recognized in the camera image since the light refracts on them, thereby causing the light beams to be reflected to the camera optics.

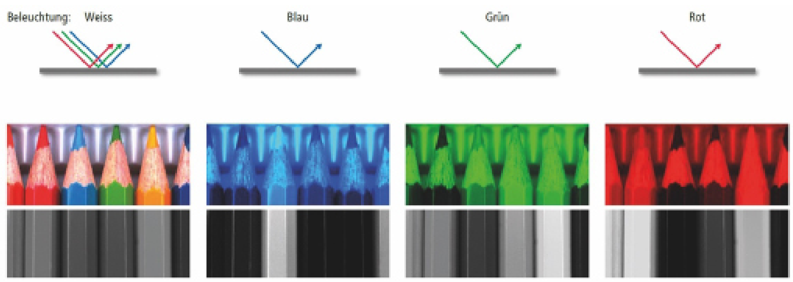


Transmissive illumination. The light is quasi-injected into a transparent test object.

6 COLORED ILLUMINATION

When speaking of the considerable influence of illumination on the test results when using camera sensors, one must also discuss the topic of "colored illumination," since colored illumination for inspecting specific product features can also influence the depiction in the camera image and, thus, the evaluation. Even with monochromatic imaging of a camera sensor, different-colored illumination (e.g., blue, green or red) can highlight or suppress specific colors. The contrast produced in the camera image by a certain colored illumination can be very helpful for distinguishing between relevant object features.

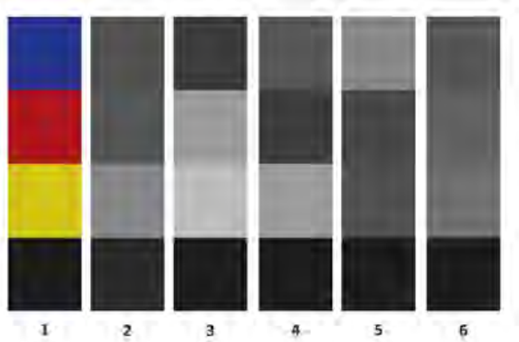
Below is an example for inspecting crayons. Let us assume that an application is to check for the presence of a blue crayon in a paintbox. Blue light is used for the check. If the blue light is incident on a multi-colored surface or multi-colored objects, such as the crayons in this specific example, only this light is reflected by the blue areas of the material surface, in this case the blue crayon. The more blue sections the object to be detected has, the more light is reflected, making its surface areas appear brighter. In the camera image, the blue crayon in the paintbox appears in high contrast compared to the crayons of other colors and can, thus, be clearly identified. For this reason, red surfaces look extremely dark when blue light is used, as can clearly be seen in the figure.



Influence of colored illumination when inspecting crayons. Even with monochrome imaging of the camera sensor, the blue crayon clearly stands out in blue light.

6.1 ILLUMINATION WITH SPECIAL LIGHT WAVELENGTHS

In this context, ultraviolet or infrared light sources are, in a sense, special illumination techniques since their wavelengths (UV light: 100 nm to 380 nm, infrared light: 780 nm to 1 mm wavelength) are used for highlighting very specific test features. In particular, images with monochromatic cameras produce both interesting as well as revealing results, as the following figure illustrates.



Influence of different-colored illumination on the display of colored surfaces (1): 2 white illumination, 3 red illumination, 4 green illumination, 5 blue illumination. With the exception of black, colors are nearly eliminated by illuminating with infrared light (6).

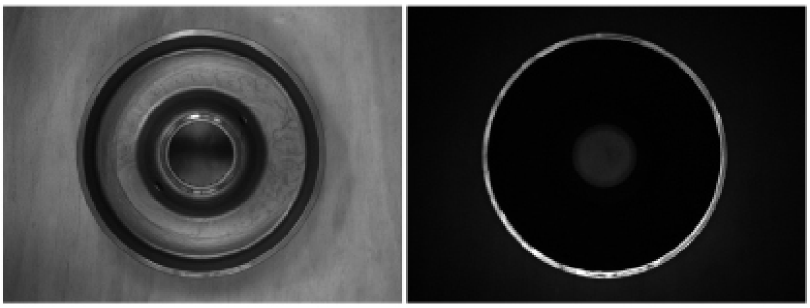
6.1.1 "SUPPRESSING" COLORS WITH INFRARED LIGHT

Infrared light is used, in particular, for inspecting the printing of best before dates or barcodes on food packaging but also for other important markings on other product packagings. Such markings are generally printed in black on packages or, alternatively, embossed. Moreover, because it is primarily food packaging that has an "attractive" product design in the form of colored figures, labels and text, the recognition of markings integrated in such designs is made more difficult for a camera sensor. Infrared light, however, eliminates nearly all colors with monochromatic imaging, thereby allowing interfering background designs on a package to be suppressed during an inspection. Meanwhile, the black product marking is clearly visible in the camera image. Caution should, however, be exercised with respect to the used printing inks as many black inks also become virtually invisible under IR illumination.

Color photo (left) and photo of a yogurt cup with a monochrome camera under white light (center). With infrared light, the colored design is nearly completely suppressed with the exception of the black writing (right).

6.1.2 UV LIGHT

A property of UV light is that it stimulates certain materials and causes them to illuminate, thereby allowing these materials to be identified in the inspection image of a camera sensor. In this context, the terms “luminescence” and “fluorescence” play a central role. Luminescence occurs as optical radiation during the transition from an excited state caused by UV light back to the original state of a material, whereby light is emitted as a result of the fluorescence during the excitation. Thus, the inspection of a specific material or object with UV light requires “pretreatment” of the object with a fluorescing agent. The aforementioned illumination disappears, however, shortly after being irradiated with UV light (original state). Additionally, the light emitted by the fluorescing material is of lower energy than the light absorbed by the material. Although the fluorescence is therefore visible with the naked eye, it is not necessarily detected by a camera sensor. The reason: Compared to the light intensity of the UV light, the illumination is weaker, causing the UV light to overpower the fluorescence in the camera image. To avoid such effects, special filters are recommended for both the camera lens as well as for the light source when using UV light sources.



Monochrome image of a bearing shaft under white light and with UV light (right) with pretreatment of the outer shaft ring with a fluorescing agent.

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