White Paper

What Needs To Be Observed When Using Camera Sensor Systems?

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Introduction

To put it in a nutshell: the use of image processing is not restricted to a single industry, because every industry has potential uses for camera sensor systems, and image processing systems open great opportunities in areas in which conventional sensors cannot be used. A wide range of different industry branches have discovered this as well, be it the automotive industry, the plastics industry, the food industry or the pharmaceutical industry, to name just a few.

The use of image processing sensor systems is possible whenever conventional sensors, such as inductive switches, optical fork light barriers, optical diffuse reflection sensors or diffuse reflection laser sensors, are pushed to their technical limits in certain applications areas. But what can image processing sensor systems do that conventional sensor solutions can't? And what, in particular, needs to be observed in their practical application?

There is a wide range of applications in which standard sensors are quickly pushed to their limits. Such sensors frequently fail if a test specimen cannot be positioned (such as on a conveyor belt), if several characteristics of an object are to be inspected (e.g., bores in a cast part), if the location of an imperfection in an object varies (e.g., multiple missing needles in a needle bearing) or if surfaces or areas need to be inspected (e.g., molded parts consisting of two components, such as seals).

"See" differently

An all-in-one image processing system such as the Opti-Check camera sensor (fig. 1) from ipf electronic consists of a camera with integrated image processing computer and complex software, a lens and an illumination unit.

What such a combination needs to perform in practical use with respect to sometimes difficult inspection tasks which are not possible with standard sensors becomes clear when one compares a camera sensor with human vision.

Fig. 1: The Opti-Check camera sensor from ipf electronic is an all-in-one image processing system

Superior to human vision?

For color vision in daylight or at dusk, the human eye has six million so-called cones. As twilight darkens or in nearly complete darkness, the 120 million rods in the eye take over due to their higher light sensitivity, whereby humans are then only able to distinguish between light and dark or black and white. In such a case, the eye can detect fewer than 100 shades of grey, corresponding to approximately 6-bit resolution.
The flicker limit of the human organ of sight, i.e., the frequency at which a series of light flashes is perceived as being a continuous light, is 16 Hz at night. Thus, in darkness, the eye can transmit 100,000 MB of visual information per second.

A camera sensor, e.g., OC53, has a resolution of 360,960 pixels (with a screen resolution of 752 x 480 pixels) and is able to detect 256 shades of grey (8 bit). The maximum number of cycles at full resolution is 50 Hz and thus exceeds that of the human organ of sight. The device transmits the image information at 18 MB per second.

No objective greyscale evaluation

Based on this, the human organ of sight appears to be superior to a camera sensor in a number of areas, such as resolution and the ability to differentiate (fig. 3). Such comparisons or evaluations can, however, also be relativized. It is true that the eye can detect even slight differences in contrast under good lighting conditions and a high level of concentration, i.e., it has a high ability to differentiate even if there is very little contrast.
This ability to perceive contrast is, however, dependent on the relative differences in brightness, while the ability of a camera sensor to perceive contrast is based on the absolute differences in brightness. The result is that the sense of sight perceives either large contrasts or subtle contrasts between certain shades of grey even though the graduations are constant. Thus, the sense of sight is not able to objectively evaluate greyscales (fig. 2).

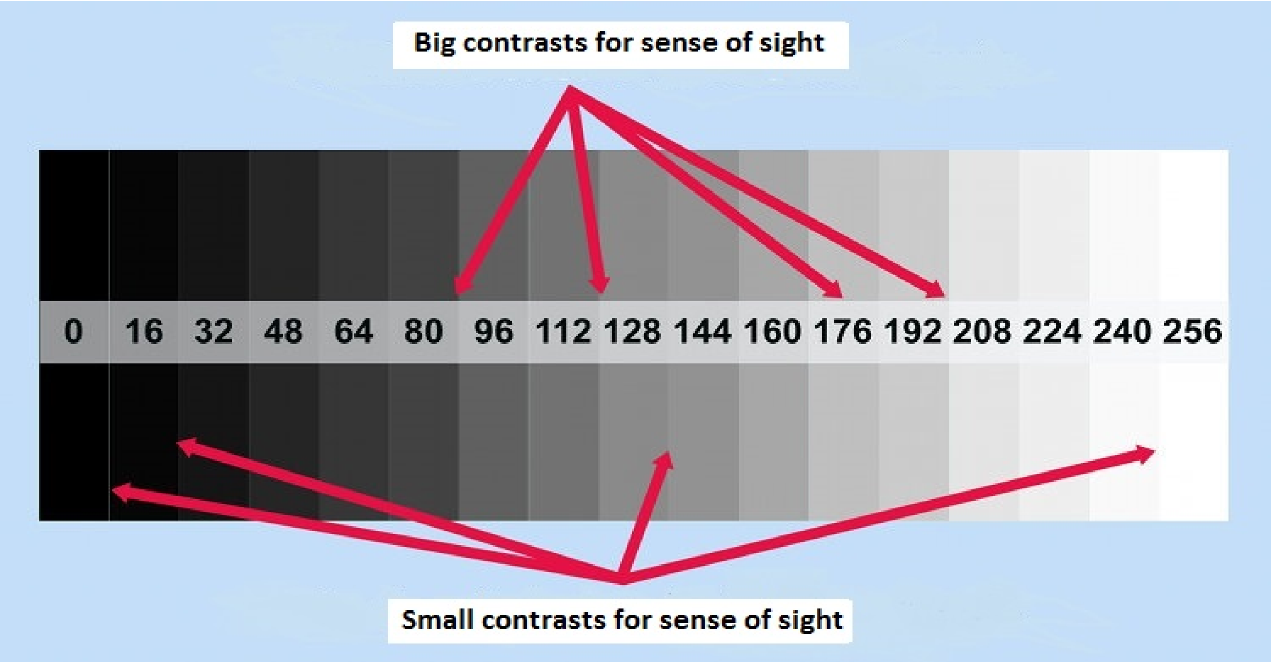

Fig. 2: The sense of sight cannot objectively evaluate greyscales.

Limited attention and quickly fatigued

In addition, the human organ of sight has a very limited attention span which is also always dependent on the "daily mood" of the viewer. The continuous visual inspection of a large number of identical objects quickly becomes monotonous and leads to an increase in misjudgments due to eye fatigue. Furthermore, the ability to see cognitively (compare with a known feature), which is required in many cases, can lead to incorrect evaluations when inspecting objects, because a known feature is read into the test specimen even though, objectively, it is not present. Last, but not least, the eye cannot see everything and is too slow in recognizing details.

Some of the ways human vision can be confused are shown in the following figure (fig. 3)

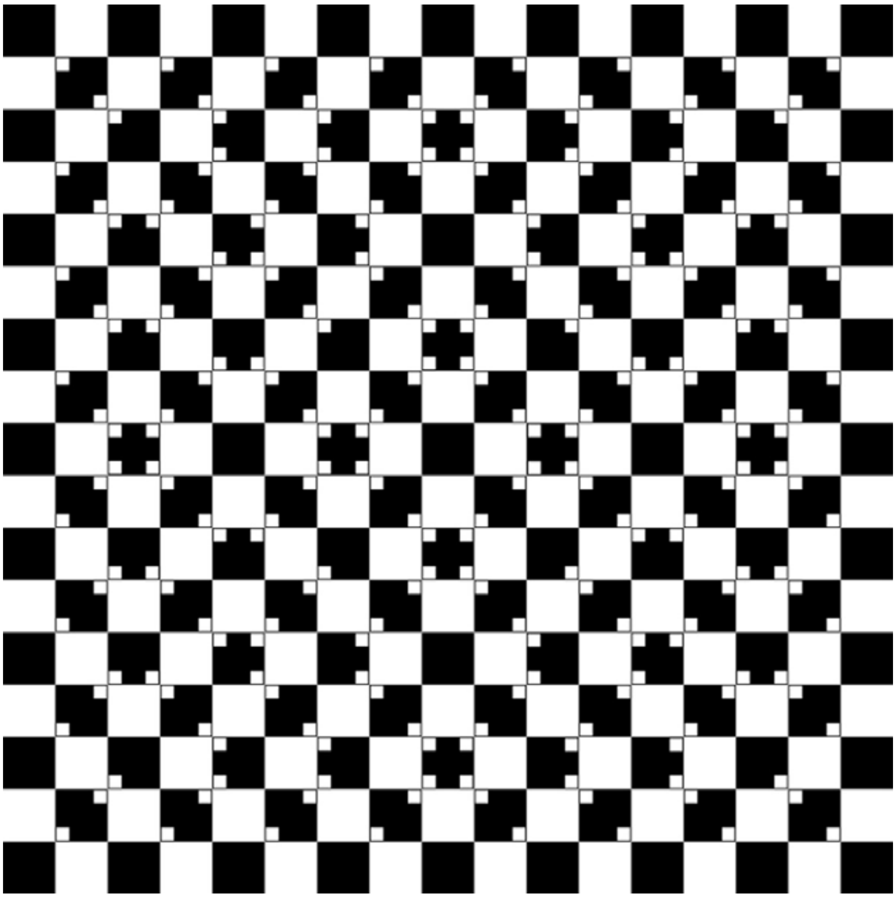

Fig. 3: The lines in this pattern do not appear to be parallel to one another. This optical illusion is caused by the white squares in the black boxes. (Source: Wikipedia)

Reliable and exact

The image processing sensor system, on the other hand, avoids such shortcomings of human sight, since it is fast and exact, detects contactlessly, and always operates 100% reliably and objectively as well as fatigue free. Thus, a camera sensor can perform particularly well in areas that are relevant for the reliable detection and evaluation of objects with large production volume in a wide range of industries – and ultimately, that is what is important.

Nevertheless, the following maxim applies in this context: ***What cannot be recognized with the eye cannot - with just a few exceptions - usually be seen with an image processing system.***

To be able to use all-in-one camera sensors such as, e.g., the OC53 in a wide range of applications in a targeted manner and, thus, successfully, it is important to take into account a number of basic influencing factors (image sensor, lens, test specimen and illumination) that determine the reliability of the system in practical use.

"Pixilated" instead of high resolution

In the area of the image sensor, aspects relevant for the reliable recognition of test objects include, among other things, the sensitivity, the color evaluation, the exposure time, etc.

The image sensor of the OC53, for example, detects the color of an object that is to be inspected in shades of grey. Here, the pixels are the smallest elements and are organized in rows and columns (e.g., with dimensions of 752 x 480 pixels). Each pixel can have a brightness from 0 (black) to 255 (white), i.e., 256 shades of grey. Thus, what the human eye sees in high resolution is represented by the image sensor in "pixilated" form, resulting in a so-called step effect on curves (fig. 4).

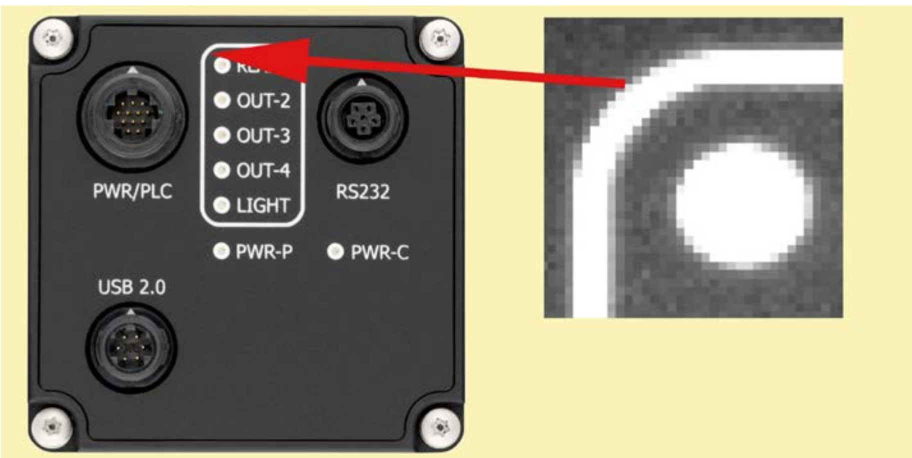

Fig. 4: A so-called step effect occurs on curves as can be seen in the magnified view at the right.

There is no perfect lens

When detecting test specimens, there is always a desire to use a camera lens to depict the specimens as true to scale as possible, in focus, with high contrast, accurate color and with uniform brightness.

But reality looks quite different. By nature, all lenses have aberrations. Special attention is therefore to be given to, among other things, distortions, perspective errors or undesired perspective effects during object recognition in combination with illumination. Such effects occur above all if test specimens are not always located in the image center of the camera's lens coverage. (Fig. 5 and fig. 6)

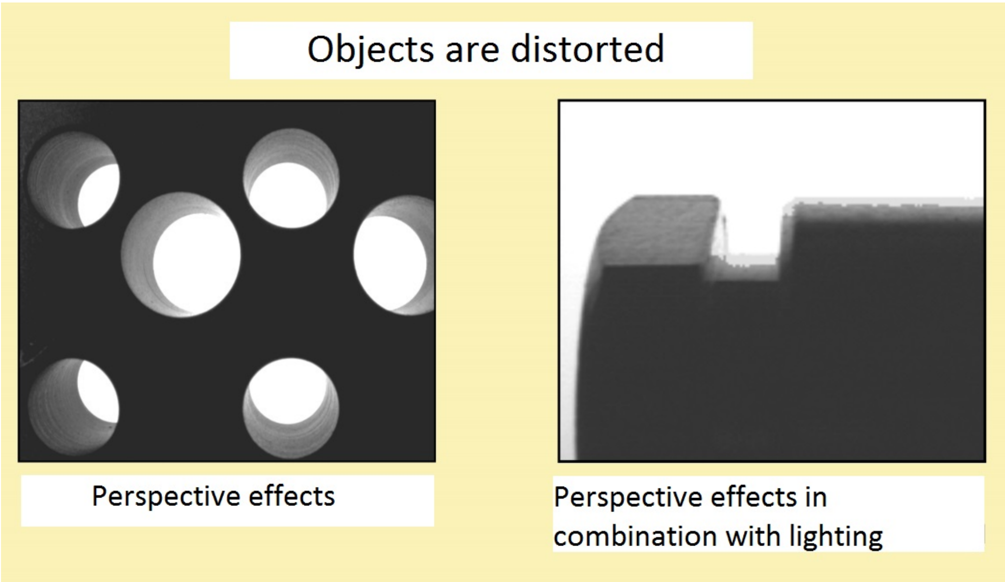

Fig. 5: The representation of the objects is distorted due to perspective effects.

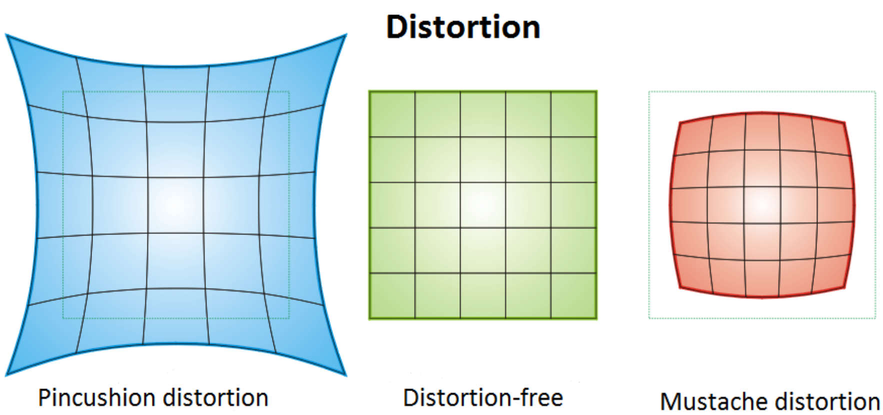

Fig. 6: The distortion depends on the image location. This has to be taken into consideration with objects that are at different positions within the image area.

Sharpest possible image representation

In the context of obtaining the sharpest possible image of a test object, knowledge of the depth of focus of lenses is helpful. Users of digital single-lens reflex cameras are familiar with this term and often also use the term "depth of field." The equation for setting the camera focus remains the same, however: the smaller the aperture opening, the greater the depth of focus, i.e., a larger distance range is in focus. The larger the selected aperture opening, the smaller the depth of focus – objects located at different distances may or may not appear in focus. This effect can only be avoided with expensive telecentric lenses.
The sharpness range referred to as "depth of focus" is, thus, the expansion of a range in the object space of an imaging optical system in which the focal plane is depicted with sufficient sharpness. This means that an object can move within the range of the depth of focus without its image on the focal plane becoming noticeably blurry.

Optimum sharpness

At a selected operating distance to the test specimen, the image sharpness can be set by adjusting the lenses of the all-in-one OC53. In doing so, make certain that all features that are to be inspected are clearly visible.
For camera sensors with a mount for external lenses (C-mount), the focus is set on the installed lens.
Because the lenses of the OC53 are extremely low distortion, a very exact inspection is possible, even in the edge area of the image.

Test specimen as an influencing factor

The movements of test objects or of a camera sensor (e.g., due to vibrations) could lead to motion blurring of the image. This effect become more pronounced the longer the setting for the exposure time of the image processing sensor. When inspecting objects that move very rapidly, the choice of the correct exposure time is decisive. Other influences caused by the test specimen may be optical, mechanical or chemical in nature (fig. 7).

Group	**Influencing factor**	**Possible reasons for changing of properties**
Optical	Parts color	Modified material
	Pattern	Modified tool
	Reflection	Modified material
		Production process
		Surface finish
	Transmission	Modified material
		Modified material
Mechanical	Edge contour	New or worn tool
	Surface geometry	New or worn tool
	Surface defect	New or worn tool
	Surface roughness	Modified quality of tool
	Chatter marks	Worn tool
	Surface finish	Alternative supplier
Chemical	Corrosion protec-tion	Strongly corroded
	Oil film	Corrosion protection
	Cutting emulsion	Alternative production process

Fig. 7: Possible influencing factors that affect the capture of a test specimen with a camera sensor.

Often underestimated: the illumination

One of the most underestimated influencing factors in image processing systems is the illumination, as its brightness and direction - among other things - have a significant influence on the image representation and, thus, the inspection result. Because the image processing algorithms "live" to a certain degree from grey value transitions, too much light can destroy the image information. To prevent a loss of information caused by overexposure or excessive saturation, the brightest grey values should always be approx. 10% less than the maximum value of 255 achieved for white when imaging a test specimen.

Selecting the correct illumination color

The color of the light also influences the representation of the surface of a test specimen as well as the representation of the background on which a test object is located. If, for example, a surface that contains the colors red, green and blue is irradiated with red light, the red area is depicted as a white surface, since the red light is reflected best from the surface here. Thus, if the surface color corresponds to the light color, this is visualized as a bright black/white representation. If, however, the object color is complementary to the illumination color, the surface is depicted as a dark black/white representation (fig. 8). Certain knowledge from the theory of color is very helpful here when it comes to selecting the correct illumination color for the purpose of obtaining a high-contrast representation of an object (fig. 9).

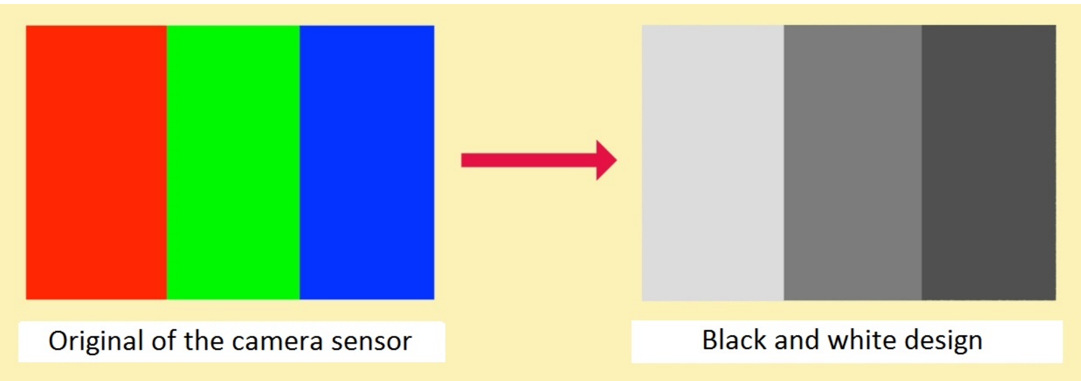

Fig. 8: If, for example, a surface with the colors red, green and blue is irradiated with red light, the red area is depicted as a white surface, since the red light is reflected best from the surface here. If, however, the object color is complementary to the illumination color, the surface is depicted as a dark black/white representation

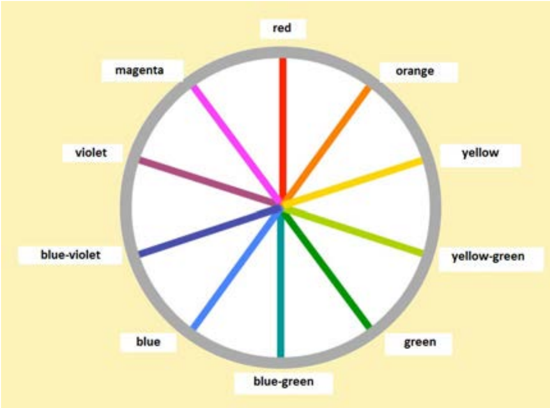

Fig. 9: Certain knowledge from the theory of color can be helpful. The figure shows a color wheel in which the complementary colors are directly opposite one another.

Photometric distance law

To correctly illuminate a test object, the so-called photometric distance law must also be taken into account. This states that the light intensity E (the luminous intensity per surface element) decreases with the square of the distance from a light source (fig. 10). For practical use, this means: the further the illumination is from a test object, the brighter the light source needs to be.

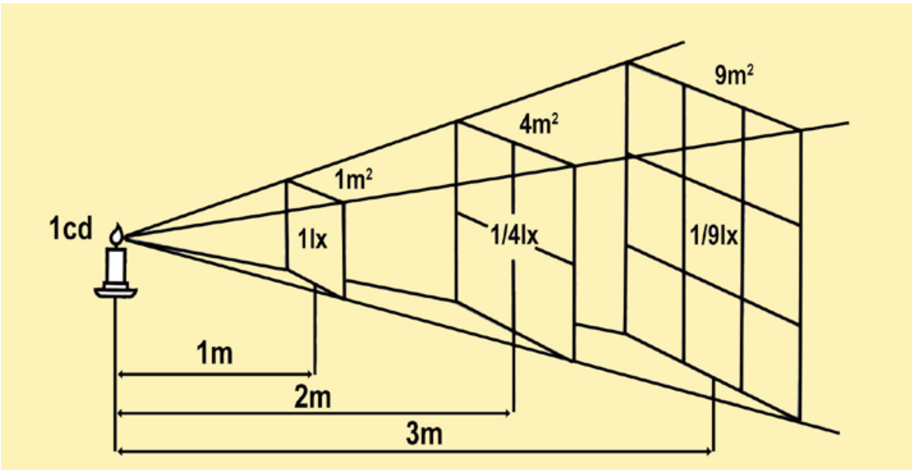

Fig. 10: The photometric distance law states that the light intensity E decreases with the square of the distance from a light source.

Summary: Illumination direction, distance, light color and brightness have a significant influence on good contrast and, thus, on reliable inspection results.

The setting of the image brightness for all-in-one camera sensors does not take place via the illumination intensity of the internal illumination, but rather via the exposure time of the image sensor. To facilitate adaptation of the sensor to a wide range of applications, two different illumination types are available (white, infrared). Especially in applications in which the camera sensor is used at manual work stations, i.e., virtually "hand in hand" with an employee, infrared illumination may be a good choice. Since this radiation lies outside of the human field of perception, the employees are not impacted in any way.