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WHITEPAPER

CAMERA SENSOR TECHNOLOGY PART 1

WHAT NEEDS TO BE OBSERVED WHEN USING CAMERA SENSORS?

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1 INTRODUCTION

To make one thing clear right away: No one specific sector is predestined to use image-processing sensor tech-nology. In actual fact, almost every branch of industry offers potential for the implementation of camera sen-sors, whereby consideration of this technology appears to be particularly worthwhile for any application where the use of conventional sensor solutions is not possible. It therefore comes as no surprise that today camera sensors are used in a great many different branches – the automotive industry, plastics industry, food industry and pharmaceutics industry to name just a few examples. The use of image processing sensor systems is possi-ble whenever conventional sensors, such as inductive switches, optical fork light barriers, optical diffuse reflec-tion 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 partic-ular, 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 devices frequently fail in situations where a test specimen cannot be positioned (e.g. on a conveyor belt), if several characteristics of an object are to be inspected in a relatively small area (e.g. bores in a cast part), if the location of a flaw on 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). The portfolio of camera sensors of the **OC53** series from ipf electronic comprises so-called compact devices and solutions with C-mount connec-tion. In addition to monochrome devices, the C-mount camera sensors with interchangeable lens also offer solutions for color evaluation. The range of compact devices too will shortly be extended to include color cam-eras. By way of an introduction to this topic, this White Paper first of all relates to the monochrome devices of the **OC53** series.

2 POWERFUL COMBINATION OF HARDWARE AND SOFTWARE

Compact camera sensors have a uniform and robust design
(degree of protection IP67) and integrate both the illumination and the lens in a single housing. The cameras offer various fixed focal distances and, depending on the device, operating distances ranging from 50mm to 300mm.
For applications that require a variable operating distance or various dimensions and types of illumination for the visual and test field, it is generally recommended to use camera sensors with C-mount lens interface. You can find additional information on this in the white paper "Camera Sensor Technology (Part 2) – New Develop-ments and Enhancements".

The powerful configuration software, which enables up to 255 inspection tasks to be created on one camera and up to 32 different object characteristics to be inspected per task, acts as a kind of interface between the user and camera sensor. What monochrome camera sensors in combination with the configuration software need to perform in practical use with respect to sometimes difficult inspection tasks which are not usually possible with standard sensors becomes clear when one compares the capabilities of such devices with human vision.

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3 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 gray, 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 to the brain.

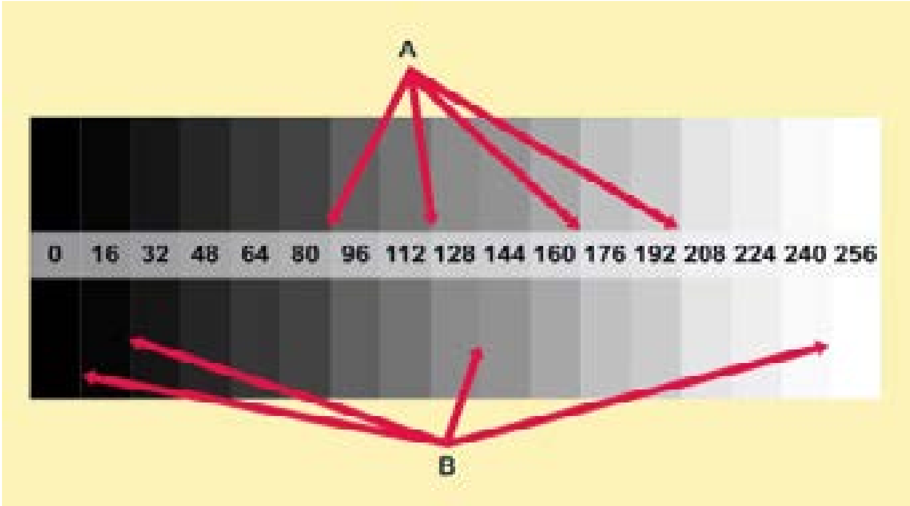
The camera sensors of the **OC53** series have a resolution of up to 2 megapixels and, as monochrome devices, are able to detect 256 grayscales (8bit). The average measuring time at high resolution is 50 fps (frames per second); at high speed, the devices achieve a measuring time of up to 100 fps.

Camera sensors of OC53 series: Compact device (left) and camera sensor with C-mount lens interface. (Image: ipf electronic gmbh)

3.1 NO OBJECTIVE GRAYSCALE EVALUATION

Under good lighting conditions and with a high level of concentration, the human eye is able to detect even slight differences in contrast, 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 gray even though the graduations are constant. The sense of sight is therefore not able to evaluate grayscales in a purely objective manner.



The sense of sight cannot objectively evaluate grayscales. A: Large contrasts for the sense of sight. B: Subtle contrasts for the sense of sight. (Figure: ipf electronic gmbh)

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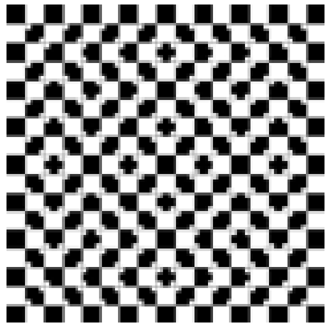
3.2 LIMITED ATTENTION AND QUICKLY FATIGUED

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.



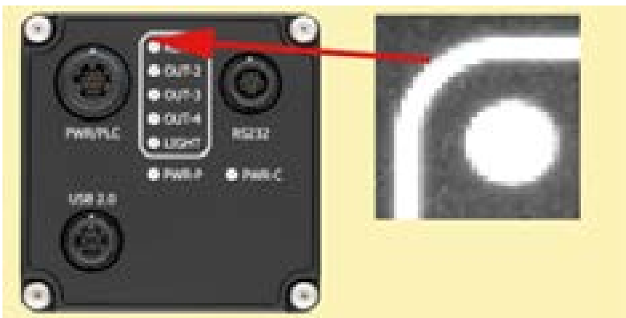
The lines in this pattern do not appear to be parallel to one another. This illusion is caused by the white squares in the black boxes. (Source: Wikipedia)

3.3 RELIABLE AND EXACT

The image-processing sensor system is not aware of such effects and influences on human vision because it is fast and exact, detects contactlessly, and always operates 100% reliably, objectively and 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. Furthermore, compared to human vision, camera sensors with their very quick measuring time are able to reliably capture and evaluate even extremely fast-moving objects.

4 "PIXILATED" INSTEAD OF HIGH RESOLUTION

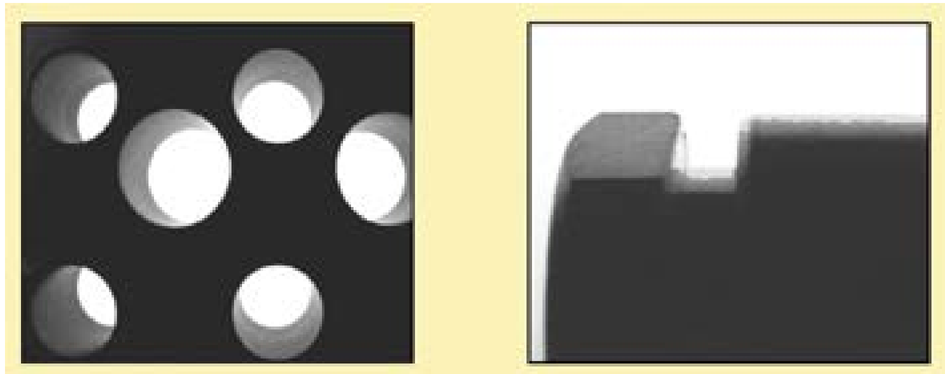
IIn the area of the image sensor, aspects relevant for the reliable recognition of test objects include, among other things, the sensitivity, the color evaluation, the exposure time, etc. The image recorder of an **OC53** monochrome camera, for example, detects the color of an object to be inspected in shades of gray (grayscales). Here, the pixels are the smallest elements and are organized in rows and columns (e.g., 720 x 480 pixels). Each pixel can have a brightness from 0 (black) to 255 (white), i.e., 256 shades of gray. Thus, what the human eye sees in high resolution is represented by the image sensor in "pixi-lated" form, resulting in a so-called step effect on curves.



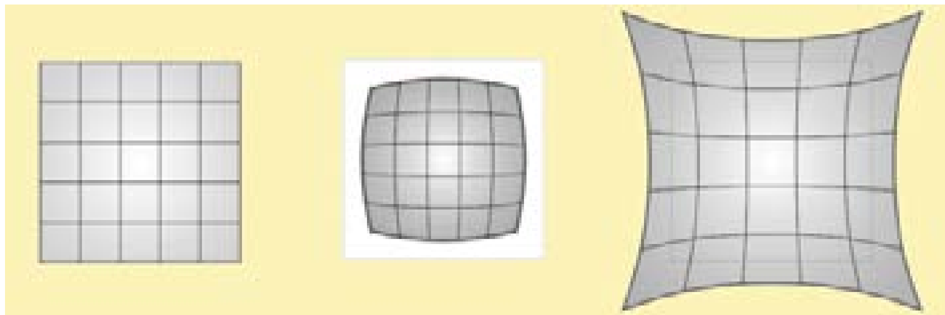
A so-called step effect occurs on curves, as can be seen in the magnified view. (Image: ipf electronic gmbh)

4.1 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 combi-nation with illumination. Such effects occur above all if test specimens are not always located in the image center of the camera's lens coverage. Camera sensors of the latest generation can compensate some of the named ef-fects during teaching of the devices (for further information, see the White Paper: Camera Sensor Technology (Part 2) – New Developments and Enhancements).



The representation of the objects is distorted due to perspective effects. (Image: ipf electronic gmbh)



Distortion: Distortion depends on the location and the angle of the camera sensor relative to the object. This must be taken into consideration in the case of objects that are located at different positions in the image area. Distortion-free image (left), barrel distortion (center) and pincushion distortion (right). (Image: ipf electronic gmbh)

4.2 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 distanc-es to the camera may or may not appear in focus. This effect can only be avoided with telecentric lenses.

4.3 OPTIMUM SHARPNESS BY SELECTING CORRECT OPERATING DISTANCE

The distance of the camera sensor to the test specimen should therefore always be selected such that the clearest possible image representation can be achieved in the depth-of-focus range. The lenses of the compact devices are adjusted to the maximum optical sharpness by manually adjusting the focus at the device. The ap-erture cannot be changed.

5 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 influ-ences caused by the test specimen may be optical, mechanical or chemical in nature.

Group	**Influencing factor**	**Possible reasons for change in properties**
Optical	Part color	Changed material
	Pattern	Changed tool
	Reflection	Changed material
		Manufacturing process
		Surface finish
	Transmission	Changed material
		Changed material
Mechanical	Edge shape	New or worn tool
	Surface geometry	New or worn tool
	Surface flaw	New or worn tool
	Surface roughness	Changed tool quality
	Chatter marks	Worn tool
	Surface finish	Different supplier
Chemical	Rust protection	Too severely corroded
	Oil film	Corrosion protection
	Cutting emulsion	Different manufacturing process

Possible factors influencing detection of a test specimen with a camera sensor.

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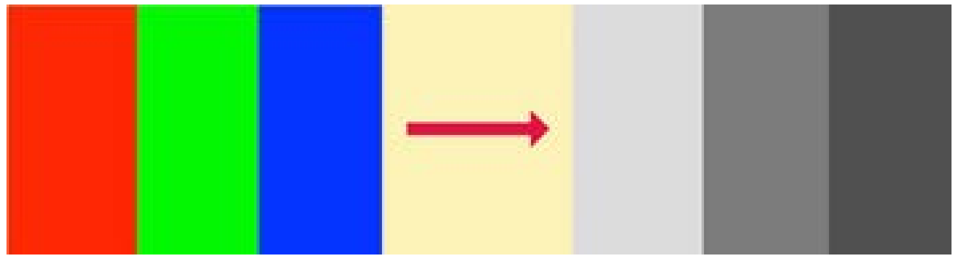
5.1 OFTEN UNDERESTIMATED: THE ILLUMINATION

One of the most underestimated influencing factors in image processing systems is the illu-mination, as its brightness and direction- among other things- have a significant influence on the image representation and, thus, the inspection result. As image-processing algo-rithms for monochrome devices „live" to a certain degree from gray value transitions, too much light can destroy the image information. To prevent a loss of information caused by overexposure or excessive saturation, the brightest gray values should always be approx. 10% less than the maximum value of 255 achieved for white when imaging a test spe-cimen. You can find more detailed information on this in the white paper "Camera Sensor Technology (Part 2) – New Developments and Enhancements".

5.2 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 repre-sentation of the background on which a test object is located. If e.g. a surface that contains the colors red, green and blue is illuminated with red light, the red area is depicted as a white surface in the monochrome camera image because here the red light is reflected the best from the surface. Thus, if the surface color corre-sponds to the light color, this is visualized as a bright white representation. If, however, the object color is com-plementary to the illumination color, the surface is depicted as a dark black representation. 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-con-trast representation of an object. You can find more information on this in the White Paper Camera Sensor Technology Part 2.

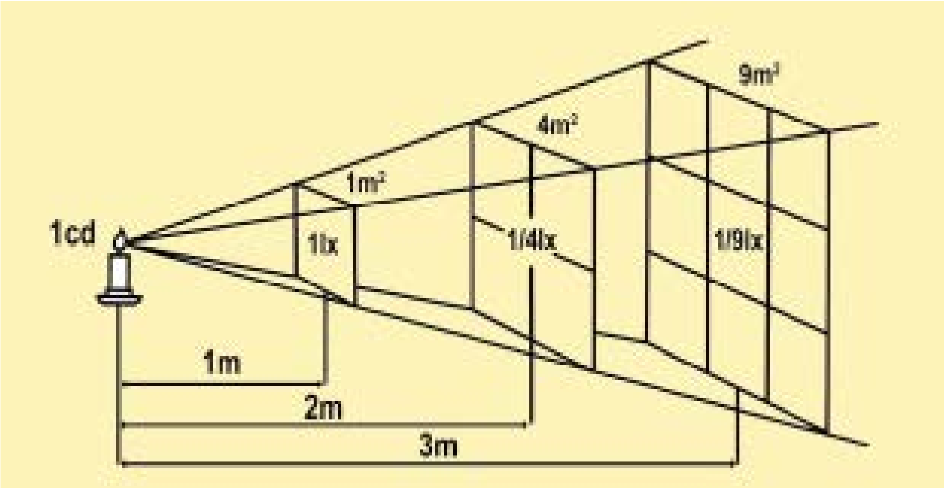


Original camera sensor image (left); black/white representation (right). If, for example, a surface that contains the colors red, green and blue is irradiated with red light, the red area is depicted as a white surface, since the red light is reflected best from the surface here. If, however, the object color is complementary to the illumination color, the surface is depicted as a dark black representation. (Figure: ipf electronic gmbh)

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.
1 red, 2 orange, 3 yellow, 4 yellow-green, 5 green, 6 blue-green, 7 blue, 8 blue-violet, 9 violet, 10 magenta. (Figure: ipf elec-tronic gmbh)

5.3 PHOTOMETRIC DISTANCE LAW

To reduce the effect of ambient light on the camera system, a bright and constant light is required for illumina-tion. In basic terms, you could say: the more intensive the artificial light is, the greater the sensitivity to ambient light will be. To intensively illuminate a test object, the so-called photometric distance law must 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. For practical use, this means: the further the illumination is from a test object, the brighter the light source needs to be.



The illuminance decreases with the square of the distance from the light source. (Figure: ipf electronic gmbh)

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