

## Making invisible visible

In some machine vision applications, it can be difficult or even impossible to make certain material properties or defects visible and thus evaluable using conventional methods. Polarization filters help in the defect inspection of material surfaces, which previously could not be detected or only with great effort. Examples where polarization can offer an advantage include:

- **The visualization of stresses in transparent materials such as glass or plastic**
- **Suppression of reflections on mirror surfaces**
- **Contrast enhancement in fiber materials, such as carbon fibers**
- **Contrast enhancement in the case of surface defects, such as scratches**

With a new type of image sensor from Sony, in which the polarization filters are applied directly at sensor level, these advantages of polarization can now be exploited much more easily and cost-effectively than before.



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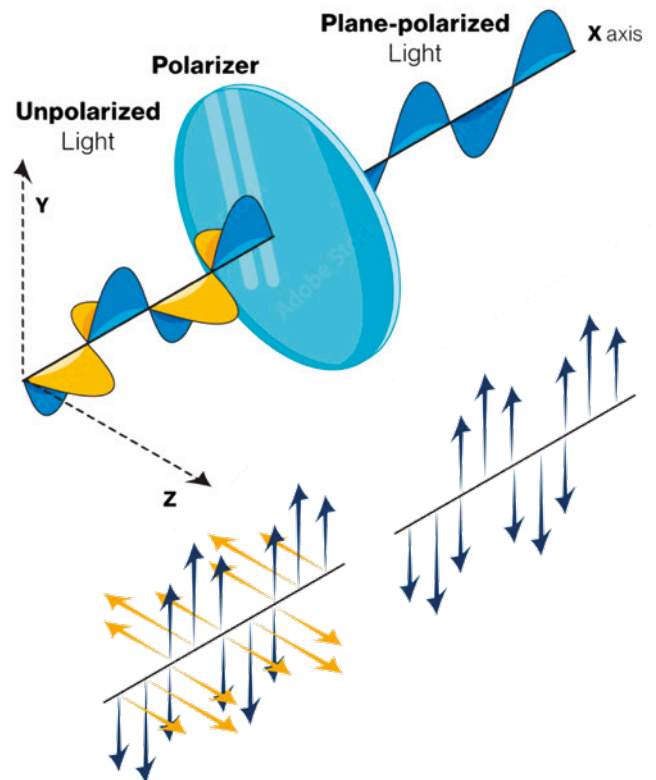
## 1.0 Technical Basics

### 1.1 Polarization in general

In addition to spectrum (color) and amplitude (brightness), polarization is another property of light waves that describes the direction of oscillation of the light waves. The majority of light sources, such as the sun or incandescent lamps emit non-polarized light. This means that the waves oscillate in different random directions. With the help of a linear polarization filter, this light can now be polarized so that only waves oscillating in a certain direction are allowed to pass through. This light is then referred to as linearly polarized light.

Polarized light can also be created in two other ways. One is by reflection from non-metallic surfaces such as glass, plastic or water. Secondly, by light refraction, i.e. when light from one medium hits another. How much light is polarized depends on the angle of incidence.

Since reflections are usually undesirable in image processing, this effect can be used to minimize reflections. Traditionally, linear polarization filters are used to eliminate the polarized part of the reflected light. The disadvantage here, however, is that the polarization can only be measured in one direction, depending on the rotational position of the filter. For different directions, mechanical rotation or changing of the filters is necessary, which is associated with relatively high costs and effort. Thus, an effective system should be able to analyze multiple polarization directions simultaneously. This has been realized in a new type of image sensor from Sony, which thus represents a simpler and more cost-effective solution.



### 1.2 Sensor

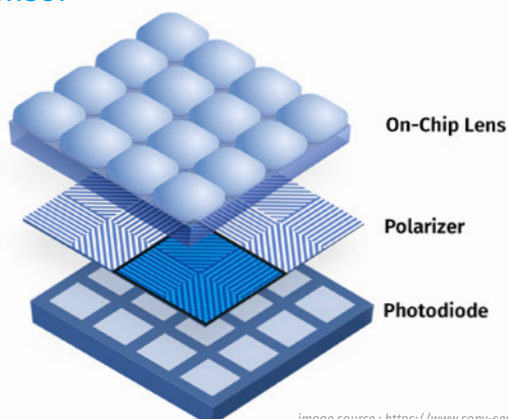
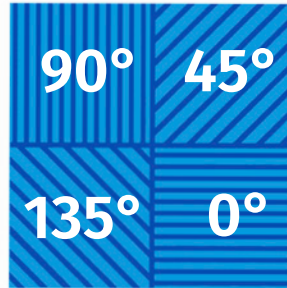


image source : <https://www.sony-semicon.com>

The unique feature of Sony's polarization sensor is that the polarization filters, consisting of nano-wire grids, are not traditionally placed in front of the lens but are directly mounted on the photodiodes. Four pixels of the sensor (arranged in a 2x2 configuration) are combined into a calculation unit in this setup.

The four polarization filters of a block are arranged in different directions (0°, 45°, 90°, 135°). This design makes it possible to interpolate both the degree of polarization and the polarization angle. The different images that can be calculated from this are described in more detail in the chapter *GigEPRO* with IMX264MZR.



## 2.0 Application examples

### 2.1 Reflective minimization on plastic packaging with V<sub>min</sub> mode



Grayscale image



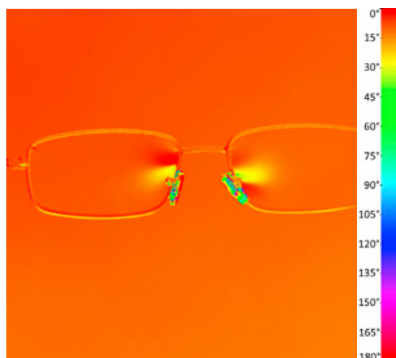
Reflection minimized image

The reflection minimization mode (see Chapter 3.2) can be used to reduce light reflections on reflective surfaces. This example clearly shows the advantage this can bring when barcodes or text are to be read through a transparent packaging film.

### 2.2 Control of residual stresses

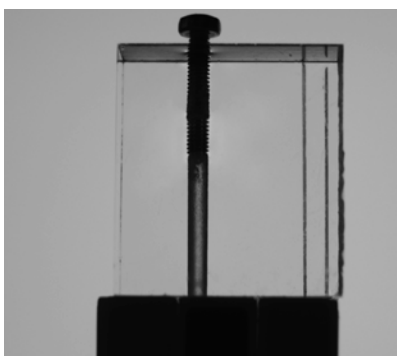


Grayscale image

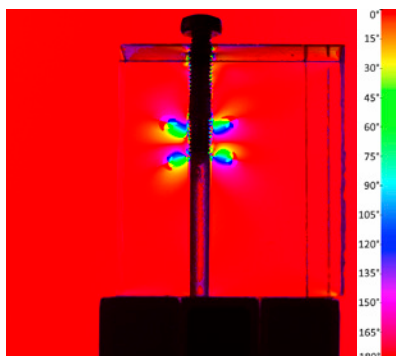


False-color image

Polarization properties can be used to make stresses in glass or plastic visible. The example of the glasses clearly shows how stresses occur in the glass in the area of the nose pads. In the second example, a screw was turned into an acrylic block. Here, too, strong stresses become visible that cannot be detected with a normal monochrome sensor.

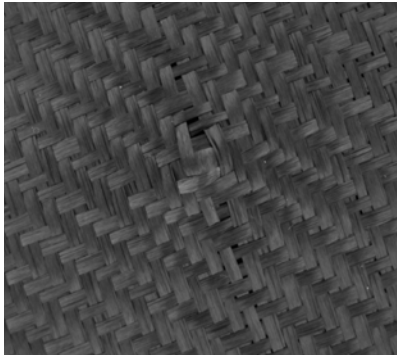


Grayscale image

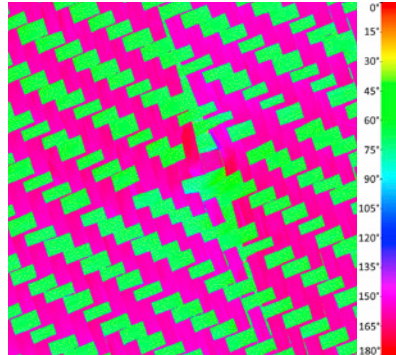


False-color image

### 2.3 Detection of defects in fibrous materials



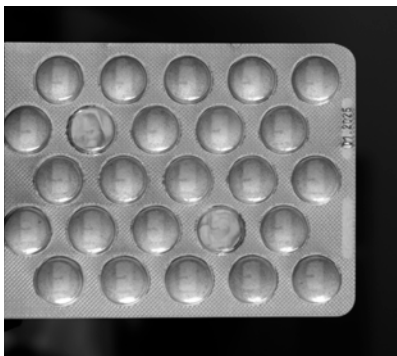
Grayscale image



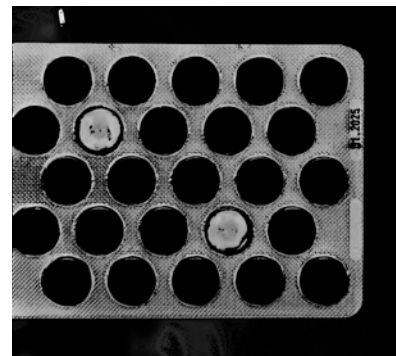
False-color image

Fiber materials also bring in a Polarization sensor has clear advantages. So you can like this in the example the fiber directions are shown clearly separated become. Thus, the strip width can be simply measure or Material defects can be detected.

### 2.4 Detection of defects in blister packs



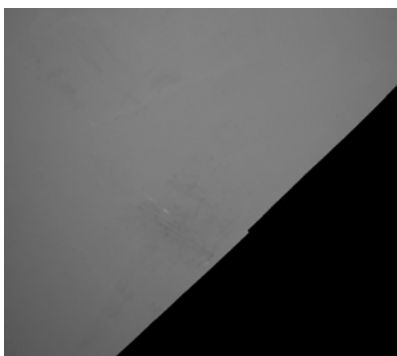
Grayscale image



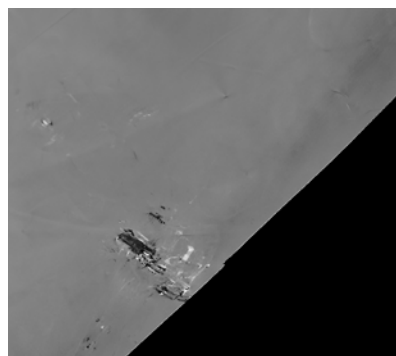
Reflection minimized image

The polarization sensor is also helpful in detecting missing tablets in blister packs. In the gray scale image, the difference between filled and empty containers is very small and difficult to detect. In contrast, in the strength of polarization (DoLP) image, there is a very high contrast between tablets and aluminum foil, which makes detection very easy.

### 2.5 Detection of damage during surface inspection



Grayscale image



Polarization angle image

The detection of surface defects is another application example where the polarization sensor can offer advantages. Here, for example, the damage to the plastic film is barely visible in the gray-scale image, whereas it stands out clearly in the polarization angle image.

### 3.0 Solution with GigEPRO camera platform

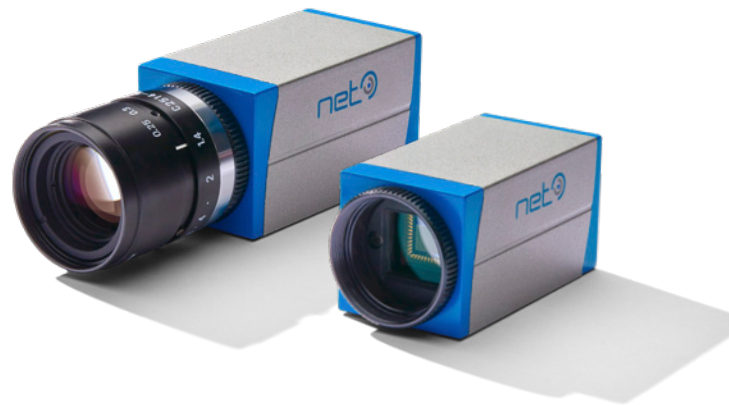
#### 3.1 GigEPRO with Sony IMX264MZR

In order to obtain result images from the raw image of the sensor (see chapter Technical Basics), it is usually necessary to calculate them on a host PC with appropriate image processing libraries. Only with these result images can polarization properties, such as polarization degree or angle, be used for further evaluation.

NET has integrated the Sony IMX264MZR polarization sensor into the **GigEPRO** camera. The special feature of the GigEPRO camera is that own algorithms can already be processed in the camera thanks to the NET Open Camera Concept. This makes the GigEPRO ideal for moving the calculation of the result images from the host PC to the FPGA of the camera. This means that no additional software library is required for the calculation and the result images can be output directly from the camera. This saves development effort, CPU computing power and software costs.

Depending on the requirements, different output images can be selected. The best known of these are the DoLP (Degree of Linear Polarization) mode, in which the degree of polarization is stored in the image as a gray value. The other is the AoLP (Angle of Linear Polarization) mode, in which the angle is stored in the gray value of the result image. Additionally, there is the possibility to output different false color modes, in which these properties are more visible to the human eye and therefore more suitable for a first viewing. Furthermore, there is a mode in which reflections are suppressed and thus an image with as few reflections as possible is displayed. If an own calculation of the result image is desired, the raw images as well as Stokes images can of course also be output. The different output images as well as the underlying processing will be explained in more detail in the following section.

**GigE<sup>PRO</sup>**



#### Technical data:

<b>Image sensor:</b>	<b>IMX264MZR</b>
<b>Resolution:</b>	<b>2464 x 2056</b>
<b>Format:</b>	<b>2/3"</b>
<b>Pixel size:</b>	<b>3,45 µm</b>
<b>Frame rate:</b>	<b>23 (Mono 8), 8 (RGB 8)</b>
<b>Shutter:</b>	<b>Global</b>

### 3.2 Output images from *GigEPRO*

#### $S_0$

The image calculated in  $S_0$  mode corresponds to an unpolarized gray-scale image as would be produced by a camera with a conventional monochrome sensor. Each pixel is determined from the average of the intensities of the 4 pixels of a calculation unit of the sensor. A calculation unit consists of a 2x2 array with the four polarization directions.

#### $S_{012}$ (Stokes 0, 1, 2)

Stokes parameters are a set of three values that describe the polarization state of electromagnetic waves (the 4th value for circularly polarized light is not important here because the sensor is not sensitive to it). These parameters are primarily used for further processing and not for visual display. The three Stokes parameters are stored in one image channel each, which can be separated later. The Stokes parameters  $S_0$ ,  $S_1$  and  $S_2$  are determined from the intensity values of the 4 pixels per calculation unit of the sensor.

$$S_0 = \frac{I_{0^\circ} + I_{45^\circ} + I_{90^\circ} + I_{135^\circ}}{2}$$

$$S_1 = I_{0^\circ} - I_{90^\circ}$$

$$S_2 = I_{45^\circ} - I_{135^\circ}$$

#### DoLP (Degree of Linear Polarisation)

The **DoLP** mode calculates an image in which the strength of the polarization is mapped in a tone value from 0 to 255. The darker the pixel, the less and the brighter the pixel, the stronger the light is polarized here. The calculation is made from the Stokes parameters according to the following formula.

$$DoLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$

#### AoLP (Angle of Linear Polarisation)

The **AoLP** mode produces an image that maps the polarization direction from  $0^\circ$  to  $180^\circ$  as a tonal value from 0 to 255. It should be noted that apparent artifacts occur here at the transition between  $0^\circ$  and  $180^\circ$ , since the angle is continuous but the tonal value jumps between 255 and 0. If this behavior is not desired for the application purpose, the Map mode should be used for the angle representation instead. The calculation is made from the Stokes parameters according to the following formula.

$$\theta = \frac{1}{2} \tan^{-1} \left( \frac{S_2}{S_1} \right)$$

#### $V_{min}$

This mode creates a reflection-reduced image. Since reflected light is polarized to a large extent, these reflections can be minimized by using the pixel with the lowest tonal value from each 2x2 calculation unit.

### Map

In Map-mode, a false color image is generated in the HSV color space, which is useful for an initial view of an object, since the polarization effects are displayed particularly clearly here. There are three variants (MapType) for this mode, which differ by different assignment of the HSV channels color value, color saturation and brightness value. The modes produce different, visual results, which are differently suitable depending on the application. The channel assignments of the MapTypes are listed in the following table.

MapType	H (Hue)	S (Saturation)	V (Value)
0	AoLP	255	255
1	AoLP	255	DoLP
2	AoLP	DoLP	S <sub>0</sub>

### Mix

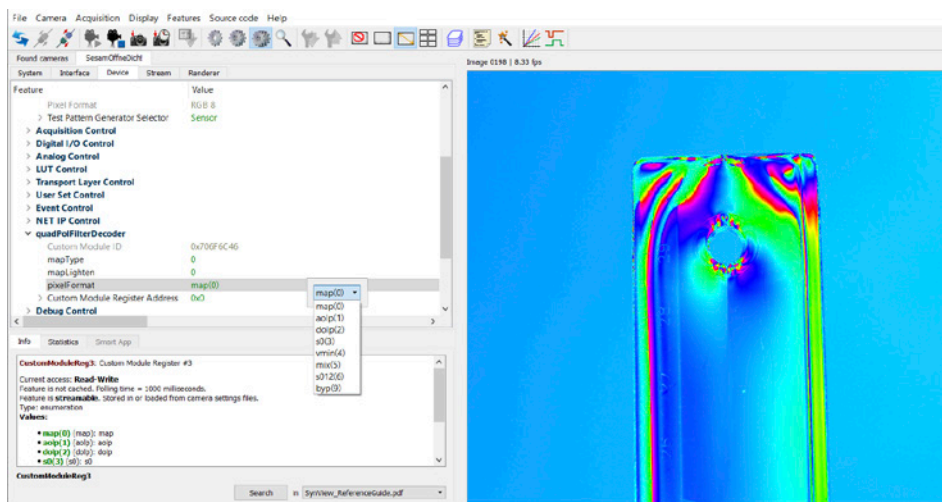
This mode is primarily used for further processing by software and not for visual display. The AoLP, DoLP and S<sub>0</sub> image are each stored in an image channel. These channels can be separated again by software and used further.

### Byp

This bypass mode provides the raw image of the sensor without any preprocessing. This gives full flexibility to perform all calculations yourself with your own software.

## 3.3 Commissioning

Due to the previously described integration of the polarization algorithms in the GigEPRO camera, the application is very simple. The connection and image acquisition is the same as for a conventional GigE Vision camera. Power can be supplied via PoE (Power over Ethernet) or an external power supply via the IO cable. By integrating it into our software interface [Synview](#), the polarization settings can be controlled directly through it. Under the **quadPolFilterDecoder** section is the **pixelFormat**, which can be used to select between the previously described image output modes.



The **mapType** and **mapLighten** settings are only active in the pixelFormat mode **map**. The mapType changes the channels of the output image as described in chapter 3.2. Since mapType 1 and 2 often produce relatively dark images, it is possible to brighten them with mapLighten to lighten them.

## 4.0 About us

### Who we are

**NET** is a leading manufacturer of individual camera solutions for industry and medical technology. Since 1996, we have specialized in the development of innovative smart vision solutions that contribute to the success of our customers worldwide.

### What we do

Our task is to contribute to the application success of our customers with vision. We see much more in the image than just an image or visualization. The image result achieved with our cameras enables beneficial human-machine interactions in medicine, facilitation of work, and increased safety and efficiency for people in industry.

### How customers benefit

NET's expertise as a product provider of innovative camera solutions for specific market and customer requirements is based on our specialist knowledge of technologies and their potential for customers in practice. In this way, we contribute to their marketing success. NET's medium-sized organization enables short decision-making paths in order to be able to respond correctly and quickly to customer requirements worldwide.

### How we work

The application knowledge of our employees combined with individual solution-oriented consulting is our core competence. It expresses how we work. We see the long-standing business relationships we have developed with many customers as confirmation of the way we work. Our focus is on sustainable vision solutions.