Allied Vision

APPLICATION NOTE

Pixel-based Polarizer

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Introduction

The Mako G-508B POL polarizer camera is equipped with the new Sony Polarsens™ 5.0 Megapixel IMX250MZR CMOS sensor that incorporates the latest four-directional polarization filter technology. The on-chip nanowire polarizing layer supports four orientations (90°, 45°, 135°, and 0°). Four pixels together build a calculation unit to determine for each pixel the intensity and angle of polarization, similar to the debayering of an RGB or color sensor. By using pseudo-color look-up tables for each angle of polarization defects and areas of stress can be easily visualized. The sensor enables polarized light imaging without optical filters.

The four-directional polarization of the IMX250MZR sensor is arranged to get transmitted light in the layout shown in the figure below. The 90° signal and 45° signal lines and the 135° signal and 0° signal lines are output successively.

90	45	90	45
135	0	135	0
90	45	90	45
135	0	135	0

Figure 1: Polarizer array coding diagram

Pixel-based polarization filters

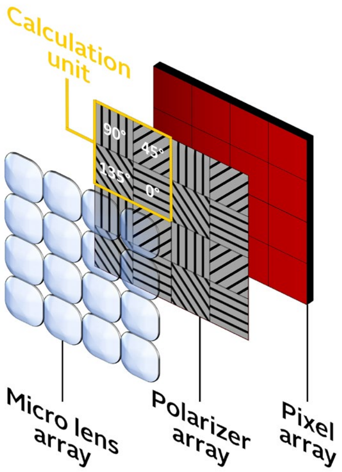

Figure 2: Polarizer array calculation unit

Figure 2 shows the polarization calculation unit in the polarizer array. The polarizer array is situated betwen the micro lens array and pixel array.

Figure 3 shows the relative pixel response by the angle of polarized light. The response of these filters to a polarized illumination would be:

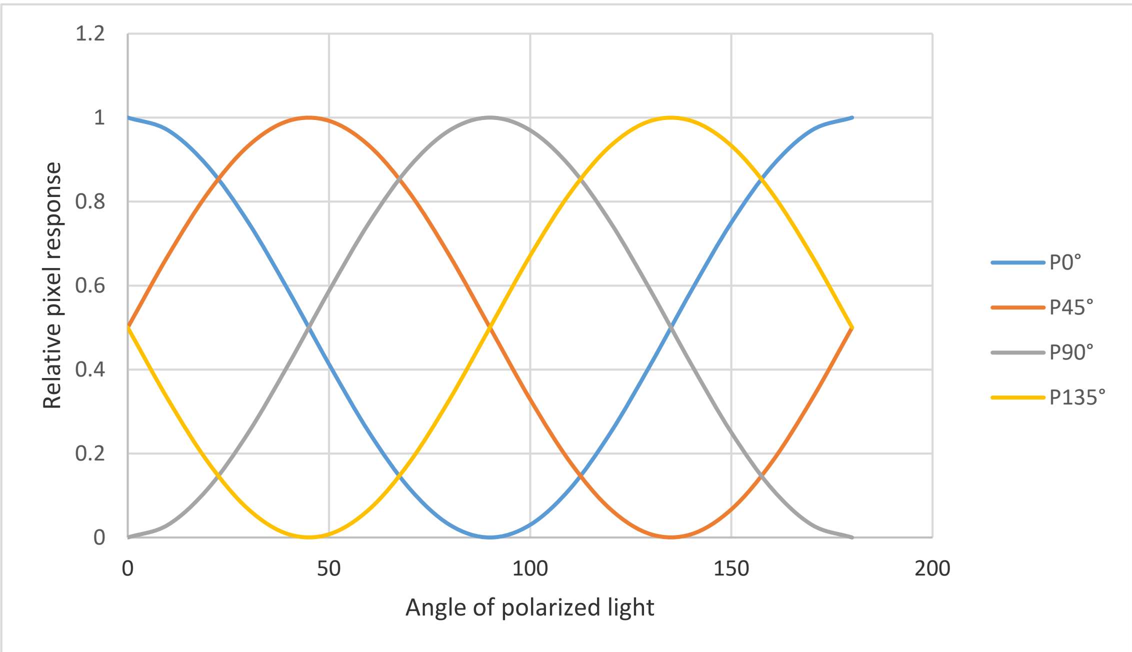

Figure 3: Relative pixel response to polarized light

The relative response with a polarized light source is: $P_{0°} + P_{90°} = P_{45°} + P_{135°} = 1$.

With an unpolarized light source, the relative response would be: $P_{0°} + P_{90°} = P_{45°} + P_{135°} = 2$.

The images in figure 4 show an example of a polarizer RAW image and its four sub-images in dependency of the orientation of the polarization filters. These sub-images have one quarter of full resolution as only one out of four pixels are used. As polarization filters block a large part of the light hitting the sensor, stronger illumination is needed for good image quality.

Figure 4: Sample of RAW polarization images and related sub-images of the four polarization directions

Polarization imaging standard operations

Stokes Parameters

One approach to quantify polarization is the usage of the so-called Stokes Parameters. These parameters cover all directions of polarization including circular polarization, which cannot be measured with the described sensor technology.

The Stokes parameters are often combined into a vector as shown in Equation 1.

$$\vec{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} P_{0^\circ} + P_{90^\circ} \\ P_{0^\circ} - P_{90^\circ} \\ P_{45^\circ} - P_{135^\circ} \\ P_{RC} - P_{LC} \end{pmatrix}; with\ P_X\ being\ the\ intensity\ of\ the\ corresponding\ pixel$$

Equation 1: Stokes parameters

Because the sensor cannot measure circular polarization (P_{RC} and P_{LC}), S_3 is always 0.

The Stokes' parameters include the angle, degree, and intensity of the polarized light.

The ranges of the Stokes parameters are:

On polarized light:

- $0.0 \leq S_0 \leq 1.0$
- $-1.0 \leq S_1 \leq 1.0$
- $-1.0 \leq S_2 \leq 1.0$

On unpolarized light:

- $0.0 \leq S_0 \leq 2.0$
- $-1.0 \leq S_1 \leq 1.0$
- $-1.0 \leq S_2 \leq 1.0$

These Stokes Parameters help you to derive other useful information from the image, including:

- Degree of polarization (p)
- Angle of polarization (θ)

The degree of polarization describes how much polarization we have at a certain pixel cluster. The degree of polarization of the reflected light depends on the material surface and the angle of reflection.

$$p = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0}, \text{with } S_3 = 0 \rightarrow p = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$

Equation 2: Degree of polarization

The angle of polarization determines the direction of reflection. The angle of polarization can be calculated as:

$$\theta = \frac{1}{2} \cdot \text{atan}\left(\frac{S_2}{S_1}\right) + n \cdot \frac{\pi}{2} \text{ with } n = 0\ if\ S_1 < 0, \text{else } n = 1$$

Equation 3: Angle of polarization

or

$$\theta = \frac{1}{2} \cdot atan2\,(S_2; S_1)$$

Equation 4: Angle of polarization

With *atan2* being the function, which already considers the quadrants of the Cartesian coordinates.

Applying the preceeding operations to the RAW image in figure 4 would result in the images shown in figure 5.

Figure 5: Degree of polarization, angle of polarization, and pseudo-color representation of polarization angles

Another interesting use case of polarization imaging data from Mako G-508B POL is the reduction of reflections. This can be achieved by applying only the lowest signal out of a calculation unit. The result of such operation can be seen in figure 6.

Figure 6: Reflection reduction by applying minimum signal of each calculation unit

Sensitivity of polarization sensors

The polarization filter applied to a pixel reduces the sensitivity of that pixel, based on two effects:

- Polarization itself
- Reduced transmission of the filter

On unpolarized light, the reduction in sensitivity caused by the polarization effect is 50 percent:

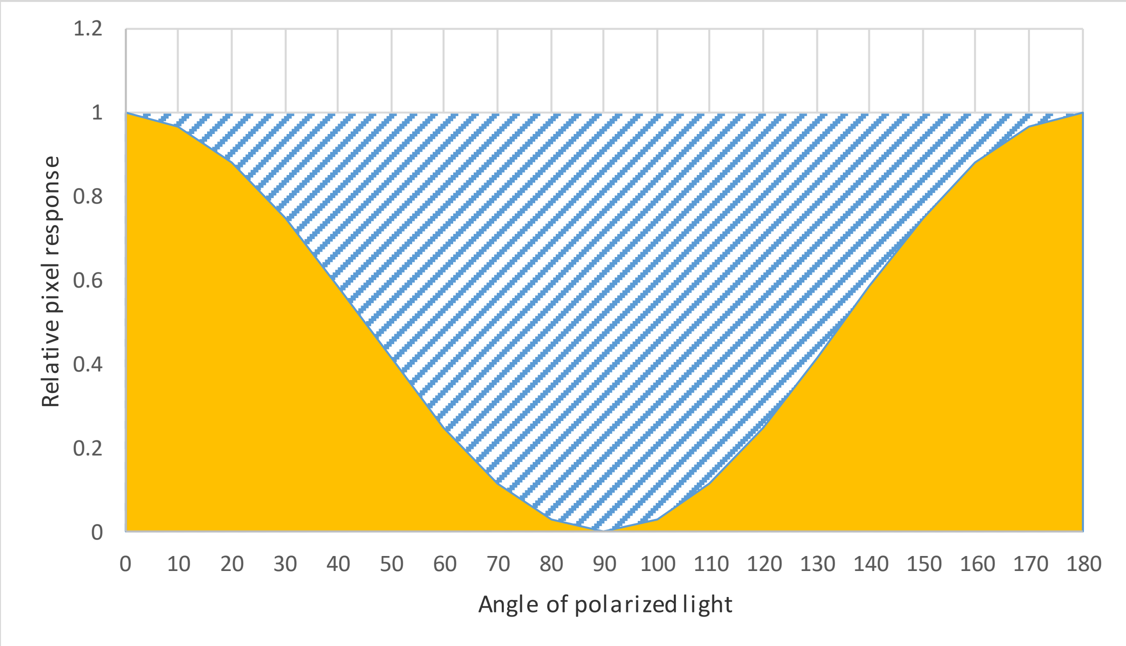

Figure 7: Sensitivity reduction caused by polarized light

Figure 7 shows that only the solid part of the light of the relative polarizer response curve will hit the sensor. This is 50 percent of the total area.

The filter transmission itself will further reduce the response.

In case of the Sony IMX250MZR sensor, the response reduction caused by the filter can be derived from the Quantum Efficiency values measured at 529 nm:

- IMX250LLR (standard monochrome sensor): 64%
- IMX250MZR (polarized monochrome sensor): 25%

The reduction due to polarization is 50% which would result in: 50% × 64% = 32%

So, the filter transmission is: $tr_{filter} = \frac{25\%}{32\%} = 78\%$

Applications

By using polarized image data, reflections that hinder a surface inspection can be reduced, contrast can be enhanced in lowlight conditions to detect shapes, and various material properties can be detected, like stress composition, or surface structure.

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