APPLICATION NOTE

Pixel Based Polarizer

V2.0.2
2025-Feb-17

Scope

Allied Vision cameras with Sony IMX Polarsens 5.0 megapixel sensors support four-directional polarization using filters directly in front of the sensor. With these cameras, you can replace additional polarizer filters on the lens used in typical applications. In many cases, polarizer sensors can adapt easily to setups with varying polarization angles; there is no need to change or rotate optical polarization filters anymore. This can be useful, for example, to reduce reflections or analyze surfaces for material stress and defects. This application note explains the functionality of polarizer sensors and shows use cases, including example images. Contents generally apply to Alvium X-507 Pol, X-508 Pol, and Mako G-508 Pol cameras.

Structure of Polarsens sensors

Figure 1 shows the structure for Polarsens sensors that is similar to that of standard sensors, but with the following differences:

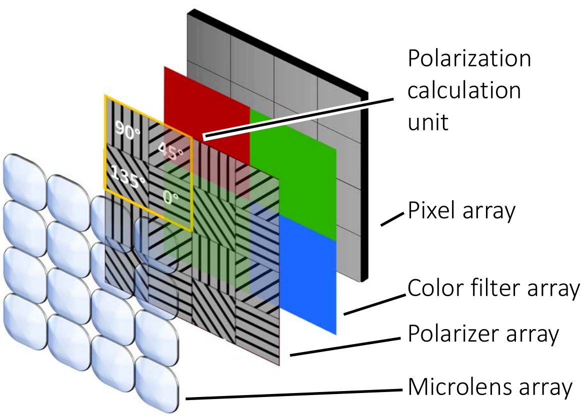

Figure 1: Structure of a polarizer sensors

- The **polarizer array** is added between the microlens array and the RGB filter array.
- Each color filter of the **RGB filter array** covers 4 pixels instead of 1 to enable polarization-related calculations.
- These calculations are carried out on the **polarization calculation unit**.

Polarizer array

The on-chip nanowire polarizer array supports orientations for 90°, 45°, 135°, and 0°. Four pixels 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.

The four-directional polarization of the Sony IMX250MZR/MYR sensors is arranged as shown in Figure 2:

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

Figure 2: Polarizer array coding diagram

Pixel response

Figure 3 shows the relative pixel response in relation to the angle of the polarized light:

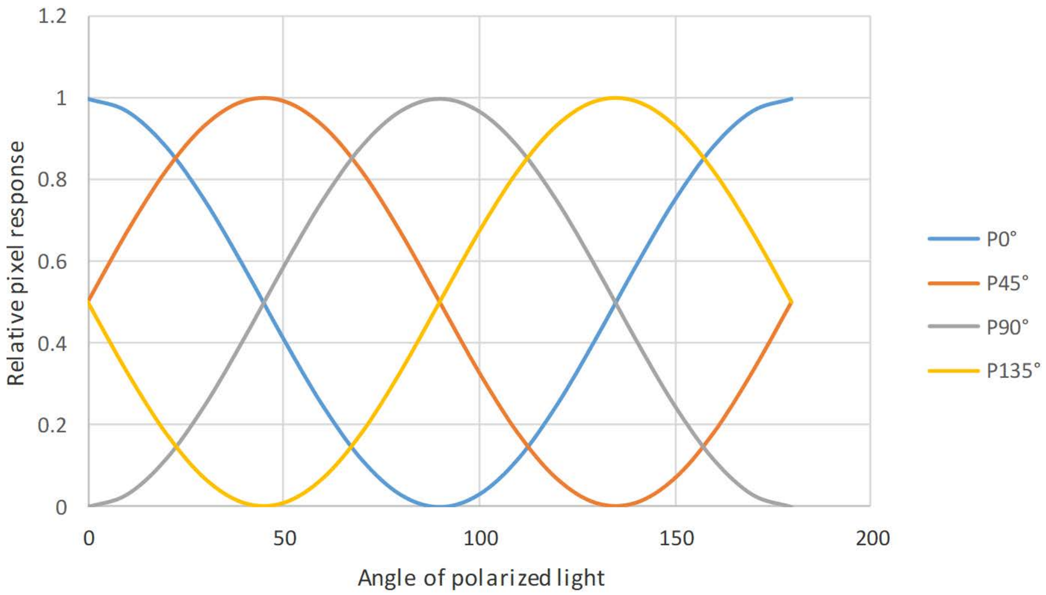

Figure 3: Relative pixel response to polarized light

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: $P_{0°} + P_{90°} = P_{45°} + P_{135°} = 2$.

Polarization angle versus image brightness

Figure 4 shows an example of a polarizer RAW image:

Figure 4: Polarizer RAW image

Figure 5 shows how the orientation of the polarization filters affects brightness values for the sub-images:

Figure 5: Polarization angle versus image brightness in sub-images

Each sub-image has one quarter of full resolution because only one out of four pixels is used.

As polarization filters block a large part of the light hitting the sensor, stronger illumination or longer exposure times are required to improve image results.

Polarization imaging standard operations

Stokes parameters

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

The Stokes parameters are often combined into a vector as shown in Equation 1. Because the sensor cannot measure circular polarization (P_{RC} and P_{LC}), S_3 is always 0.

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

Equation 1: Stokes parameters

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

The ranges of the Stokes parameters are **on polarized light**:

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

The ranges of the Stokes parameters are **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 direction of reflection is determined by the **angle of polarization**. It can be calculated like this:

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

Equation 3: Angle of polarization

Or the **angle of polarization** can be calculated like this:

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

Equation 4: Angle of polarization

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

Sensitivity of polarization sensors

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

- Polarization itself
- Transmission of the filter.

On unpolarized light, the polarization causes a reduction in sensitivity of 50 percent.

The gray area in Figure 10 shows light that does not hit the sensor. Only the light represented by the yellow area hits the sensor. This is 50 percent of the total area:

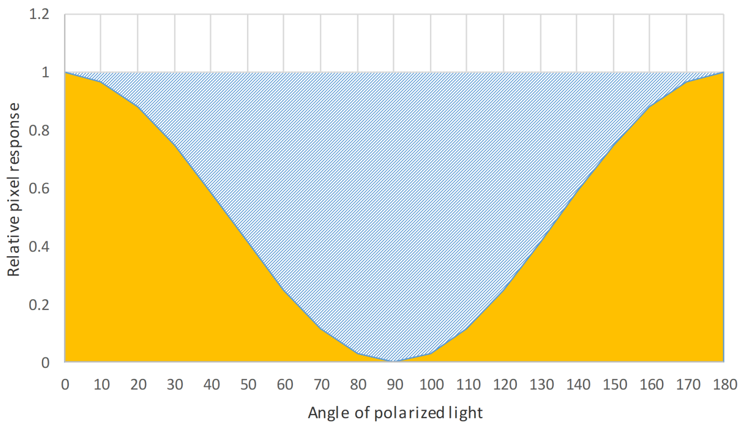

Figure 6: Sensitivity reduction caused by polarized light

The transmission of the filter further reduces 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%, resulting in: 50% × 64% = 32%

So, the filter transmission is: $tr_{filter} = \dfrac{\text{Quantum efficiency (polarized monochrome sensor)}}{\text{Reduction by polarization}} = \dfrac{25\%}{32\%} = 78\%$

Application examples

Polarization can be used for various imaging applications.

Reducing reflections

Another typical use case of polarization imaging is to reduce reflections. This can be achieved by applying only the lowest signal out of a calculation unit. The result can be seen in Figure 7.

Figure 7: Reflection reduction by applying minimum signal of each calculation unit

Other applications

Polarized image data can be used to:

- Enhance contrast to detect shapes in lowlight conditions
- Inspect material properties, such as stress composition or surface structure.
- Observe aerosol concentration and distribution of particles in gases or cloud characteristics.
- Optimize signal transmission and reception in wireless communication systems.

Contact us

Website, email

General
www.alliedvision.com/en/contact
info@alliedvision.com

Distribution partners
www.alliedvision.com/en/avt-locations/avt-distributors

Support
www.alliedvision.com/en/support
www.alliedvision.com/en/about-us/contact-us/technical-support-repair-/-rma

Offices

Europe, Middle East, and Africa (Headquarters)
Allied Vision Technologies GmbH
Taschenweg 2a
07646 Stadtroda, Germany
T// +49 36428 677-0 (Reception)
T// +49 36428 677-230 (Sales)
F// +49 36428 677-28

North, Central, and South America, Canada
Allied Vision Technologies Canada Inc.
300 – 4621 Canada Way
Burnaby, BC V5G 4X8, Canada
T// +1 604 875 8855

USA
Allied Vision Technologies, Inc.
102 Pickering Way- Suite 502
Exton, PA 19341, USA
Toll-free// +1-877-USA-1394
T// +1 978 225 2030

Asia-Pacific
China
Allied Vision Technologies Shanghai Co Ltd.
B-510, Venture International Business Park
2679 Hechuan Road
Minhang District, Shanghai 201103
People's Republic of China
T// +86 21 64861133

Japan
Allied Vision Technologies
Yokohama Portside Bldg. 10F
8-1 Sakae-cho, Kanagawa-ku
Yokohama-shi, Kanagawa, 221-0052
T// +81 (0) 45 577 9527

Singapore
Allied Vision Technologies Asia Pte. Ltd
82 Playfair Rd, #07-01 D'Lithium
Singapore 368001
T// +65 6634 9027

Copyright and trademarks