White Paper

Polarization-Based Industrial Cameras: Basics and Applications

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Content

Four-directional, On-chip Polarizing Sensor with Global Shutter

Sony recently introduced its first polarized sensors featuring the novel Polarsens™ technology. These sensors create images of physical properties that are otherwise not visible using standard imaging sensors. Using a Pregius CMOS (5.0 MP: IMX250) sensor as a base, Sony has integrated a polarization array *between* the on-chip micro lens and the pixel array (Fig. 1, below).

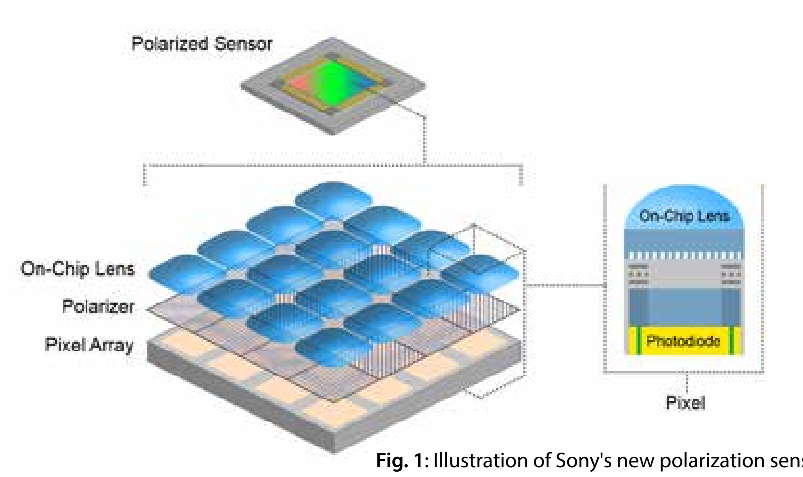


Fig. 1: Illustration of Sony's new polarization sensor

A four-directional polarization image is achieved by dividing the polarization array into four different wire-grid directions (90°, 45°, 135°and 0°) - with one grid section per pixel (Fig. 2, right).

Using this method means all linear angles of polarized light can be detected by comparing the light intensities captured by each pixel in a four-pixel block (i.e. the *Calculation Unit* shown in Fig. 2).

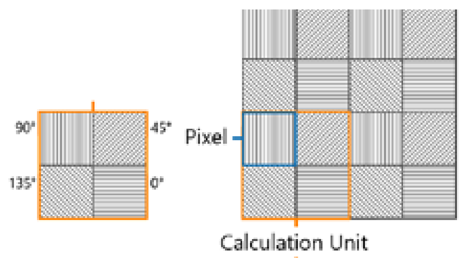


Fig. 2: Polarization array with detail.

Significantly, Sony's polarization sensor can capture a four-directional polarization image in *one shot* (Fig. 3). Additionally, the degree of polarization and the polarization angle can be calculated in real-time at high frame rates.

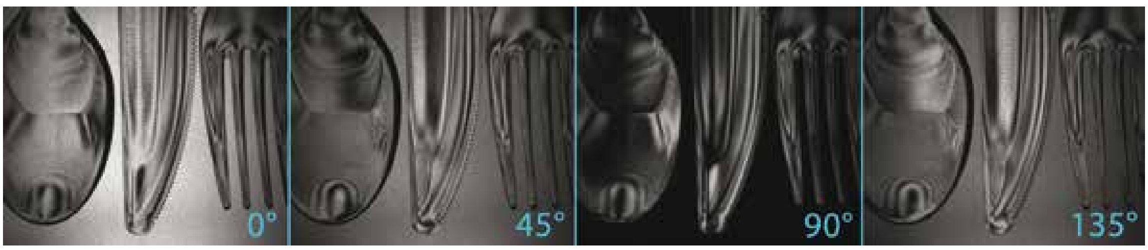


Fig. 3: Four-directional polarization information captured in one shot.

What is Polarized Light?

Light waves are electromagnetic waves. The strength of the electric and magnetic field changes spatially and temporally in a periodic fashion. These variations are responsible for the physical properties of brightness (amplitude), color (wavelength) and polarization (direction of oscillation). Light which oscillates at all angles (rather than in a single plane) is called unpolarized light. Light from virtually all natural light sources is unpolarized.

Polarization filters work by allowing only waves oscillating at particular angle (e.g. vertical or horizontal) to pass through (Fig. 4).

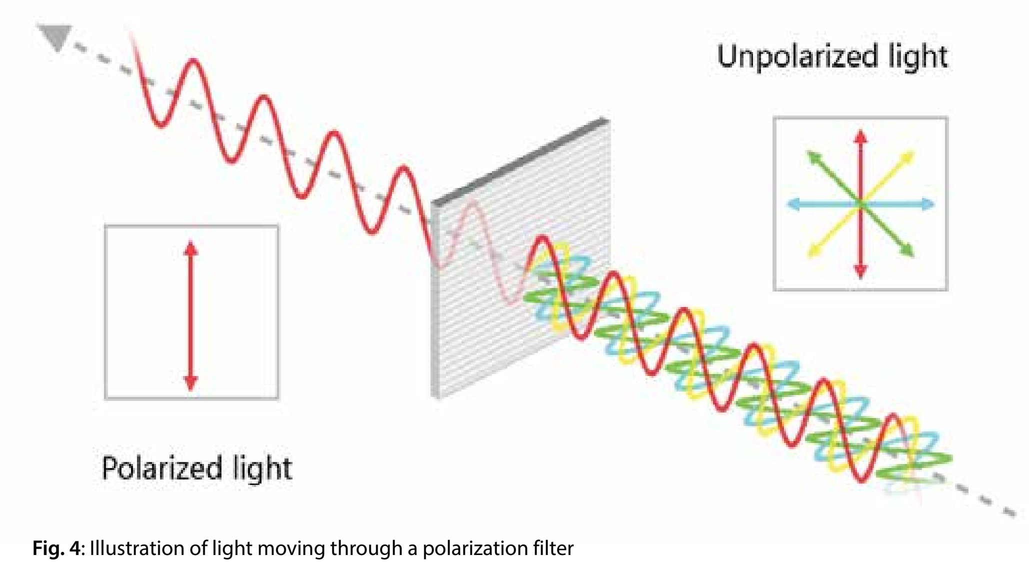


Fig. 4: Illustration of light moving through a polarization filter

As above in Fig. 4, the light waves passing through the sensor's wire-grid polarizer are restricted to one plane and are, therefore, called linearly polarized light.

Unpolarized light can also be polarized by surface reflections from non-metallic surfaces. Other materials, such as plastic or semi-transparent surfaces, such as glass or water, reflect and polarize only a certain portion of the light.

Linear polarized light only oscillates in one plane. The polarization direction and the degree of polarization are physical information that can be used for many applications such as scratch detection, particle inspection or shape recognition.

Stokes Parameter

The physical information of polarization can be described as *degree of linear polarization* (DoLP) and *angle of linear polarization* (AoLP).

The "Stokes-Parameter" is used to determine the polarization state from the intensities of the different polarizers of a four-pixel block.

In the case of linear polarized light, the parameters read:

$$S_0 = I = P_{0^\circ} + P_{90^\circ}$$
$$S_1 = Q = P_{0^\circ} - P_{90^\circ}$$
$$S_2 = U = P_{45^\circ} - P_{135^\circ}$$

Based on the Stokes parameters, two important properties can be calculated: Degree of linear polarization (DoLP) and angle of linear polarization (AoLP).

Polarization-based Industrial Cameras:
Degree of Polarization

Degree of Linear Polarization (DoLP)

The degree of polarization, *Π*, indicates the ratio of the intensity of the polarized to the intensity of the unpolarized part of the light:

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

In the case of totally polarized light, this corresponds to the total intensity of the light. In case of unpolarized light, this corresponds to zero.

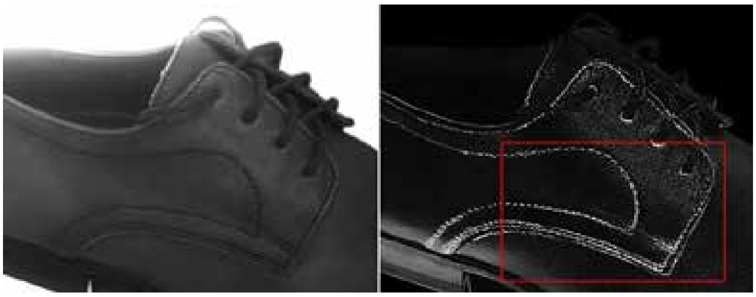
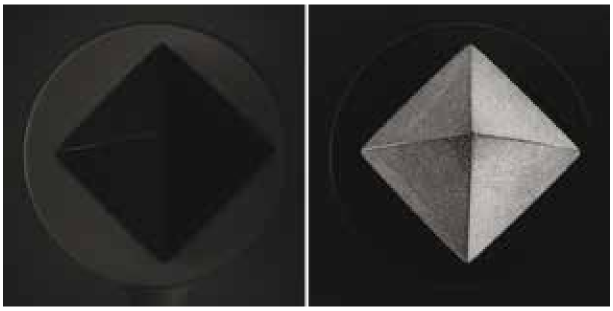


Fig. 5 (left): Left image made with standard imaging sensor. On the right, DoLP processing of the polarization data dramatically improves the contrast between the leather and stitching.

Fig. 6 (right): Shows a standard intensity image (left) of a black granite pyramid with low overall contrast. The right image from DZK 33UX250 results from DoLP processing of the polarization data.



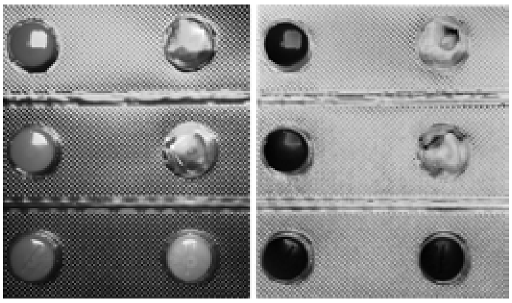


Fig. 7 (left): Shows a standard intensity image (left) of medication in blister pack with low contrast and glare. The right image from DZK 33UX250 (DoLP processing) shows improved contrast and significant glare reduction, making presence inspection more accurate..

Using standard vision sensors, such low-contrast images (figures 5, 6, and 7: left images) deliver limited visual information. The polarized degree images (DoLP processing: right images), on the other hand, clearly show the areas of high polarization (light) and regions of low polarization (dark), creating enhanced contrast and glare reduction.

Angle of Linear Polarization (AoLP)

The direction of the maximum polarization is defined by:

$$\Theta = \arctan \frac{S_2}{S_1}$$

The polarization direction provides information about the object plane (surface normal) that reflects the incoming light. In order to display the polarization information, HSV color mapping (Fig. 8) is used. The polarization direction is stored in the hue channel and the degree of polarization is stored in the saturation channel. In this way, the polarization data's irradiance information is preserved.

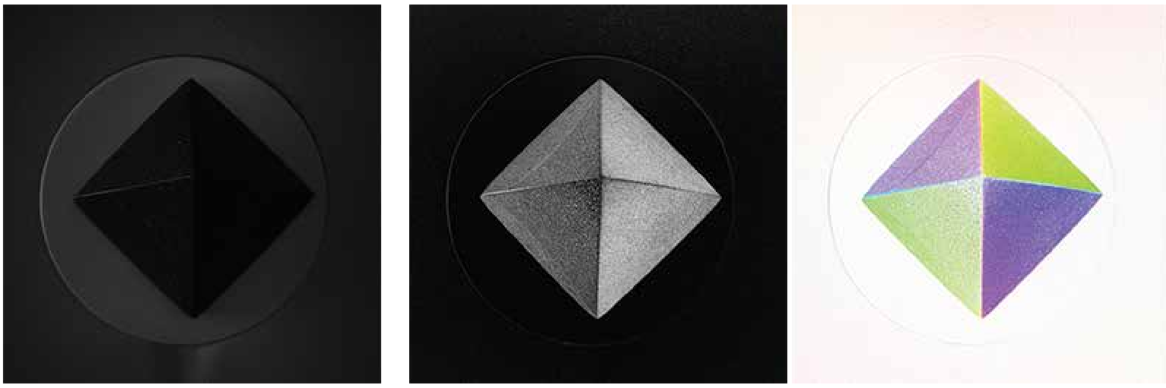


Fig. 8 Intensity image (left) displays poor contrast overall. DoLP processing of the polarization data (middle) adds contrast; AoLP processing of the polarization data with HSV color mapping (right) from DZK 33UX250 adds additional image information which can be used for effective segmentation.

In the above example (Fig. 8, right), the right side of the pyramid is colored bright green which according to the color sphere (Fig. 9) means that the angle of the polarization direction is a slightly less than 90°.

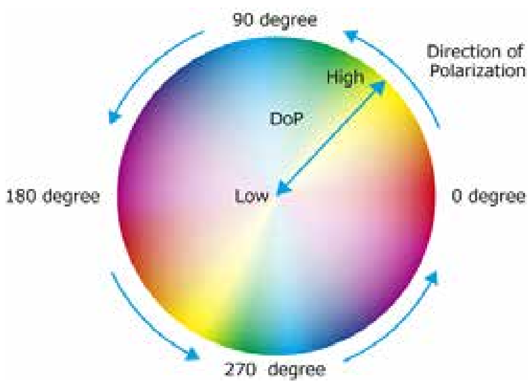


Fig. 9: HSV color mapping

Stress Inspection

Sony's four-directional, on-chip polarization sensor can be used for many industrial inspection tasks (e.g. distortion inspection) to evaluate stress (birefringence) in transparent materials—all without the need for traditional polarization plates or multi-camera setups (one for each direction of polarization).

Because the sensor captures four linear polarizations at once (producing elliptically or circularly polarized light), particularly stressed areas of an object can be dynamically visualized under mechanical stress in real-time.

The image below (Fig. 10) shows stress-induced birefringence with transparent objects.

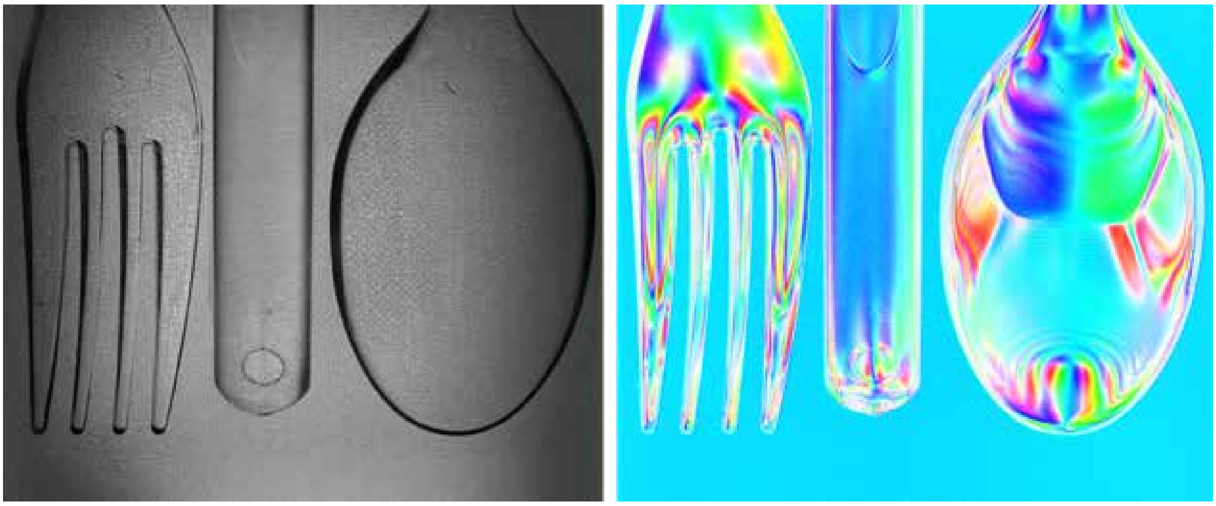


Fig. 10: Intensity image (left). Image from DZK 33UX250 (right), using AoLP processing of the polarization data and HSV color-mapping to show residual stress in plastic (birefringence).

Scratch Inspection

With conventional methods, it can be difficult to identify defects or irregularities in material surfaces, such as scratches. Polarized images can help detect such defects (Fig. 11, below).

Other inspection challenges may include highly-reflective or low-contrast surfaces.

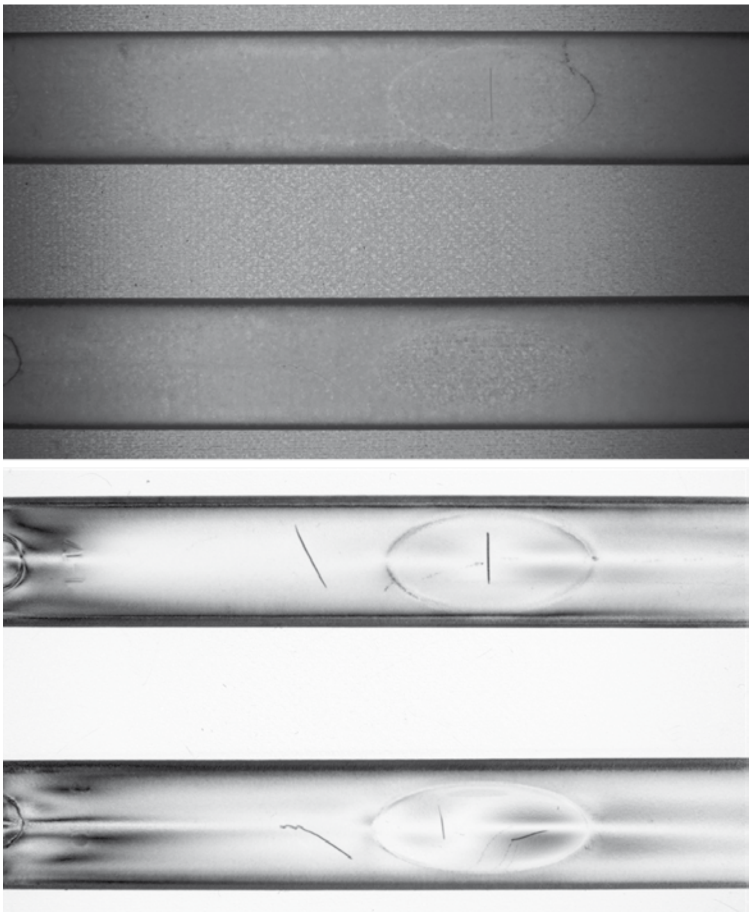


Fig. 11: Intensity image (top) shows little contrast, making visualization of defects difficult. Bottom image made with DZK 33UX250 using DoLP processing shows improved contrast,making scratches visible

Polarization-based Industrial Cameras:
Applications

Surface-reflection Elimination

Polarization information can be used to suppress unwanted reflections from smooth, non-metallic surfaces.

Light with vertical polarization is reflected with greater intensity from non-metallic surfaces when the angle of reflection is between 30° and 40° to the surface (close to the Brewster angle). If the polarization filter is correctly aligned, the reflected light waves are suppressed. This allows an elimination of disturbing reflections from windows and water surfaces.

Using the four-directional wire-grid polarizer on the polarization sensor, it is possible to remove reflections in multiple planes.

This is shown in the example picture (Fig. 12, right): Not only the reflections from the windscreen of the car are reduced, but also those from the side windows.

Fig. 12: Top image: Image from standard sensor showing heavy surface reflection.
Center image: Image from four-directional polarizing sensor with reflections eliminated.
Bottom: image with color mapping

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