exo250Z polarized camera

Scale your vision.

The new exo250Z with Sony's IMX250MZR sensor captures polarization information

Introducing a new world

Introducing the exo250Z polarization camera

Apart from brightness and wavelength, the polarization is part of the fundamental properties of light. Our exo250Z camera with the new IMX250MZR Sony sensor can capture polarization information which cannot be detected by conventional imaging devices. This opens the door to novel applications in industrial machine vision applications and beyond. Prominent examples include the analysis of the orientation of carbon fibers, the visualization of tensions in glass caused by stress induced birefringence, the reduction of reflections and glare or simply the enhancement of contrast between materials that are difficult to tell apart with conventional imaging modalities.

What is Light Polarization?

Machine Vision applications often rely on the automatic analysis of digital images. The images themselves contain information on the interaction of light with the materials of interest. The type of information captured in the images is dependent on the image acquisition technology employed. The digital monochrome or color camera in combination with adequate optics might be most commonly used in industrial machine vision implementations. They capture the intensity distribution and, in case of the color camera, additionally information on the wavelength of the reflected or transmitted light of the objects of interest.

It should be appreciated that light carries additional information that can be used to probe target objects. The lights electromagnetic waves are characterized by their intensity, wavelength, phase and polarization. With our new polarization camera, information on the spatial distribution of the polarization state of light can actually be captured.

The polarization is a property that characterizes the geometrical orientation of the oscillation of the electric field of light. Linear polarized light, for example, is light that oscillates only in one plane perpendicular to the direction of propagation. Figure 1A visualizes a linearly polarized wave of one wavelength. Additionally, the figure shows circular polarization (Figure 1B). It can be obtained by transmitting linear polarized light through optical active media for instance . In this paper we will focus primarily on linear polarized light.

Light that we encounter in our natural environment from most common light sources is typically unpolarized, i.e. the light consists of a multitude of waves with oscillation orientations that are statistically distributed (see Figure 1C, left). An interesting effect occurs when this unpolarized light gets reflected off dielectric materials such as glass. These materials show a reflectivity that differs for polarization components that are polarized parallel to the surface normal of the material compared to the components that are polarized perpendicular to it. The difference in reflectivity is dependent on the reflective index of the material as well as on the incident angle. Thus, the reflected light typically shows a partial polarization (Figure 2C, right). Incident light at a specific angle, the so called Brewster angle, has the interesting property that only polarization components perpendicular to the surface normal are reflected, resulting in linear polarized reflected light (Figure 1D).

[1] Simply put, linear polarized light can be thought of as an addition of two coherent waves along two orthogonal directions. An optical active media can show a different refractive index for polarizations along these two directions, such that the two partial waves propagate with different speed through the media and acquire a phase difference. The addition of these two phase shifted waves results in elliptical or circular polarization, as the resulting electric field vector turns in an elliptic or circular pattern (Figure 1B). Circular polarization is obtained for a phase shift of exactly ±90°.

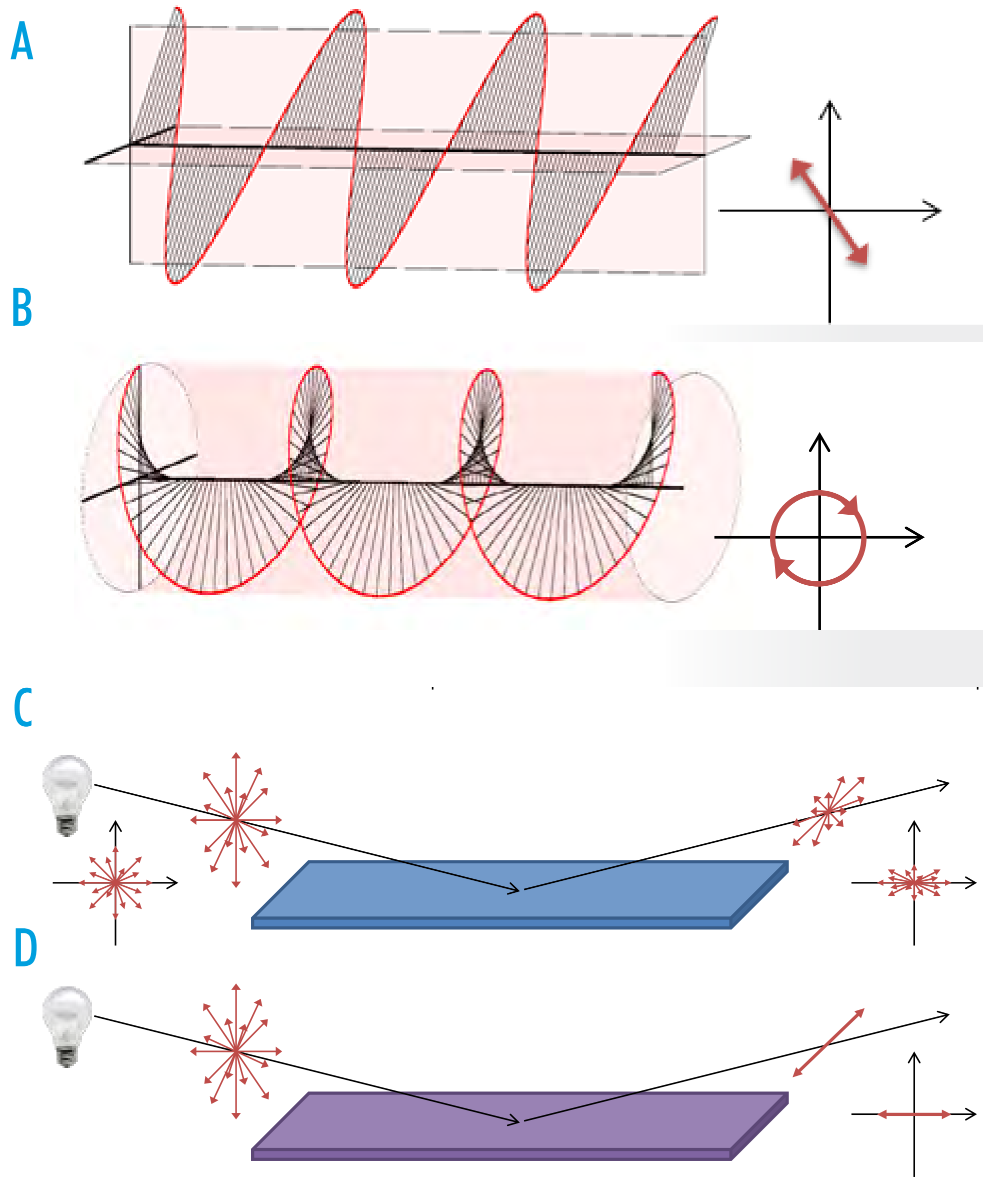

Figure 1: (A) Left: Linear polarization at 125°. Right: 2D representation of the electric field vector for a complete cycle. (B) Left: Circular polarization. Right: The 2D representation of the electric field vector for a complete cycle describes a circle. (C) Left: Light from multiple sources, as obtained from the sun or incandescent light bulbs, consists of multiple wave trains. They generally show intensity and oscillation orientations that are statistically distributed, so called unpolarized light. Right: Reflection at the interface of dielectric material. The reflectivity of the polarization component that is parallel to the surface normal differs from the polarization component that is perpendicular to it. Thus, the resulting polarization is not unpolarized anymore but partially polarized. (D) For a specific angle that is material dependent, only the polarization component that is parallel to the surface normal gets reflected. This angle is called the Brewster angle.

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Measuring the polarization

In order to characterize the polarization of light, linear polarizers can be used. It is an easy and efficient way to obtain linear polarization from unpolarized light. Multiple realizations of polarizers exist and explaining them all would surpass the scope of this paper. Here we want to focus on the grid polarizer. This is an optical element consisting of an array of subwavelength parallel metal nanowires. The component of the incident electric field that is polarized parallel to these metal wires is blocked in a way that only the polarization component perpendicular to the nanowire grid is transmitted (Figure 2A). These nanowire grids are employed in our exo250Z camera.

Our exo250Z camera series utilizes the newly developed 5 MP IMX250MZR Sony sensor. This sensor is based on the popular 2448 x 2049 pixel, 2/3" IMX250 CMOS sensor with 3.45 μm pixel size. A four-directional polarization square filter array is overlaid directly on top of the pixel array and beneath the micro lenses (Figure 2C, D). This filter consists of repeated 2x2 patterns consisting of grid polarizers with four different angles at 0°, 45°, 135° and 90° (Figure 2D). Each polarizer filters the incoming light so that only the polarization components perpendicular to the grid orientation can pass through and be detected by the underlying photodiode. Thus, a four directional polarization image can be captured in one shot.

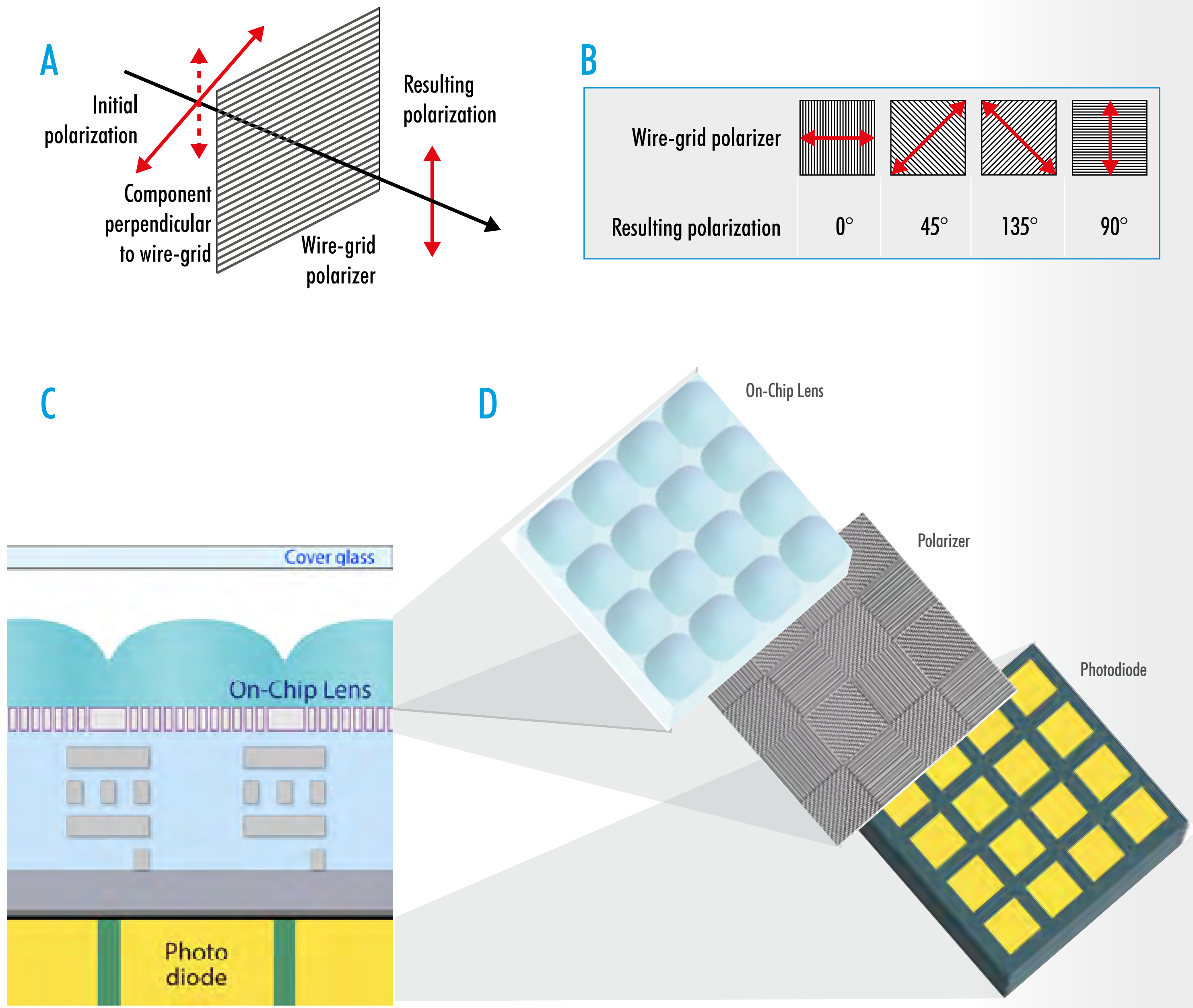

Figure 2: (A) A grid polarizer blocks the polarization component that is parallel to the grid array. Only light perpendicular the grid can pass through. (B) Grid polarizers with different grid orientations result in linear polarized light with orientations perpendicular to the grid orientation, respectively. Here grid orientations of 0°, 45°, 135° and 90° are shown. (C) The IMX250MZR sensor has a polarization filter array added to the photodiode array. A short distance between polarizer and the photodiode reduces the effect of crosstalk, i.e. the wrong detection of a polarization angle by a neighboring pixel. The sensor shows excellent image quality in various light source environments. (D) The polarization filter array consists of multiple 2x2 patterns that show four different wire grid orientations. The respective measured signal I of a 2x2 pattern is a measure of the amount of light with 0° (I_0), 135° (I_{135}), 45° (I_{45}) and 90° (I_{90}) polarization. These intensities can be used to estimate the angle of linear polarization Θ as well as the degree of linear polarization DoLP. Images in C and D are adapted from Sony.

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In subsequent post processing, the 5 MP image can be used to obtain four size reduced images (1.25 MP) filtered by one polarization filter, respectively. Additionally, the images can be used to estimate the spatial distribution of the brightness of the average of each 2x2 pattern, as well as the associated linear polarization angle Θ and the degree of linear polarization DoLP (Figure 3).

The pixel intensities I of a 2x2 pattern are a measure of the amount of light with 90° (I_{90}), 135° (I_{135}), 45° (I_{45}) and 0° (I_0) polarization, respectively (Figure 2B). Addition and Subtraction of these intensities are known as Stokes Parameters[2]:

$$S_0 = I_0 + I_{90}$$
$$S_1 = I_0 - I_{90}$$
$$S_2 = I_{45} - I_{135}$$

Conveniently, the polarization angle Θ and the degree of linear polarization DoLP are easily computed from the Stokes parameters[3]:

$$\Theta = \frac{1}{2}\operatorname{atan}\left(\frac{S_2}{S_1}\right) \qquad DoLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$

Examination of these values provides an imaging contrast enhancements in a multitude of applications compared to standard camera imaging, as shown in the following application examples.

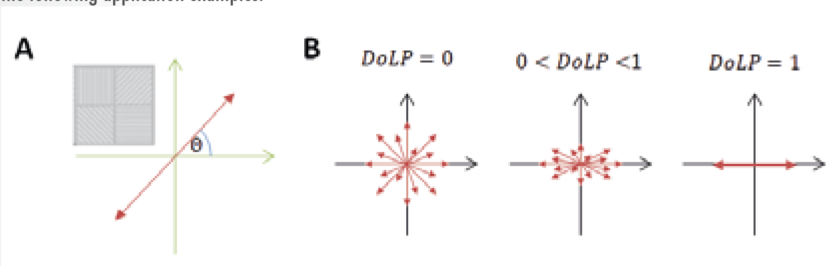


Figure 3: (A) Angle of polarization Θ as compared to the orientation of the 2x2 four-directional polarization pattern. (B) Degree of linear polarization (DoLP) is zero for unpolarized light and one for perfectly linear polarized light. In the case of light with partial polarization, a value between zero and one is obtained.

[2] Please note that the fourth Stokes parameter $S_3 = I_R - I_L$, which is calculated from the intensities of right and left circular polarized light, cannot be obtained from the image.

[3] The inverse tangent needs to be computed such that it returns values in the closed interval [-180°,180°].

[4] Please note that the degree of linear polarization does not quantify the amount of circular polarized light. Perfectly circular polarized light will have a value of DoLP = 0. Nevertheless, a multitude of applications do not require the estimation of the circular polarization.

Application examples

Calculation of the spatial distribution of the polarization angle Θ as well as the degree of linear polarization DoLP increases the information content of the measurement. Many applications exist for such measurements, for examples the analysis of the orientation of carbon fibers, the visualization of tensions in glass caused by stress induced birefringence, the reduction of reflections and glare or simply the enhancement of contrast between materials that are difficult to tell apart with conventional imaging methods. Subsequently, some application examples are shown.

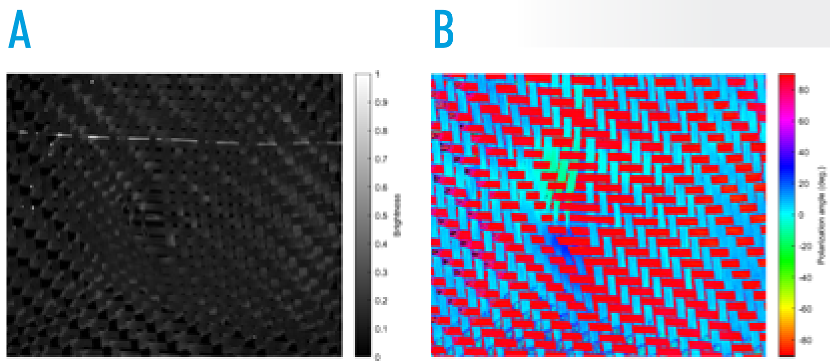


Figure 4: (A) Monochrome camera image. (B) The polarization angle allows the estimation of the carbon fiber orientation. Additionally, potential errors in a carbon fiber grid can easily be detected.

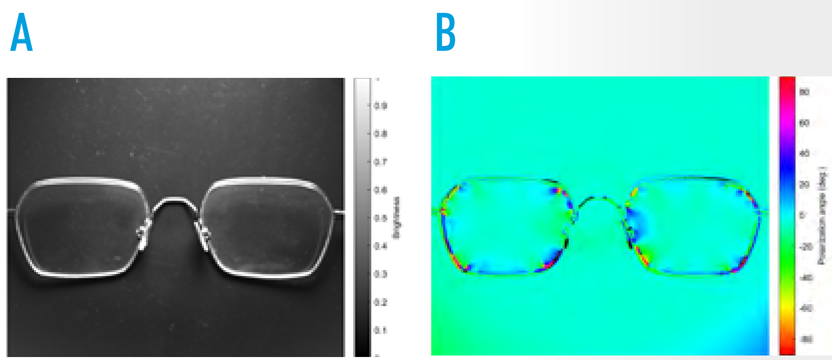


Figure 5: (A) Monochrome camera image of spectacles. (B) Tensions in the glass induce birefringence that alter the polarization angle of the light and can thus easily be visualized. .

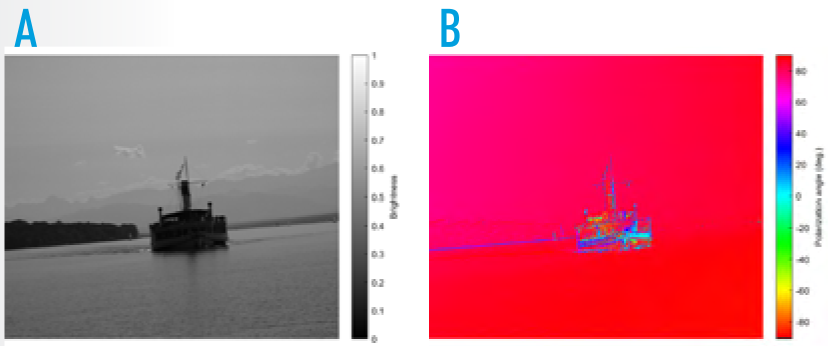


Figure 6: (A) Monochrome camera image of a daylight scene in nature. (B) Examination of the polarization angle allows an easy separation of the boat in the water from the scene.

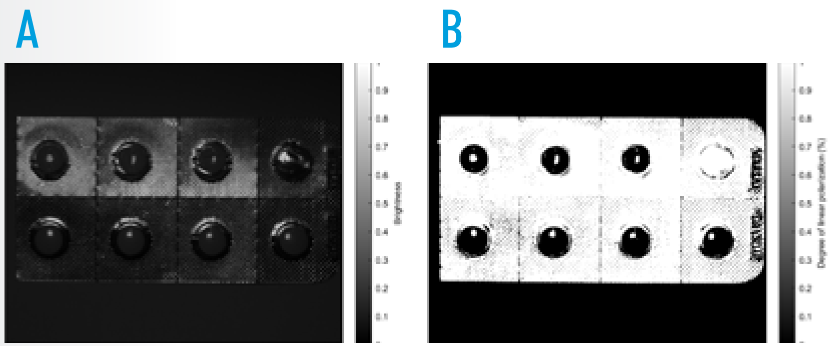


Figure 7: (A) Monochrome image of a pack of pills. (B) The aluminum pack reflects the linear polarized light, whereas the reflection from the pills results in unpolarized light. Thus, the degree of linear polarization shows a strong contrast between the pill and the package. The missing pill can easily be identified.

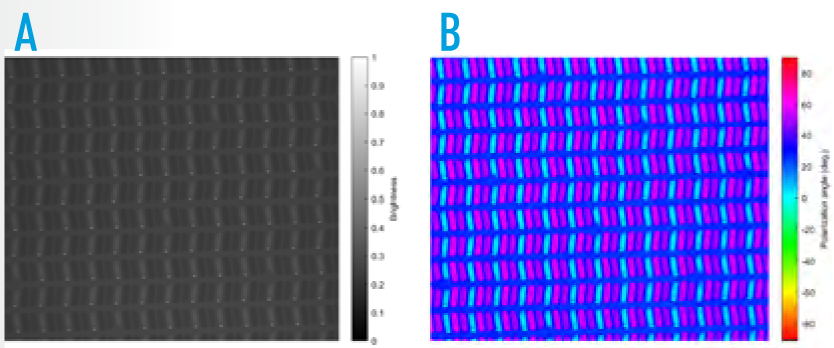
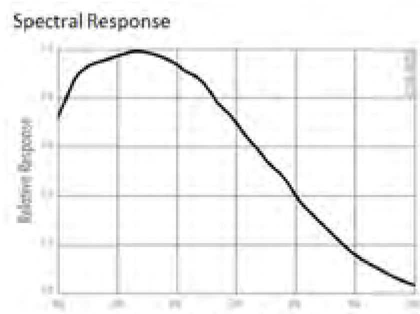
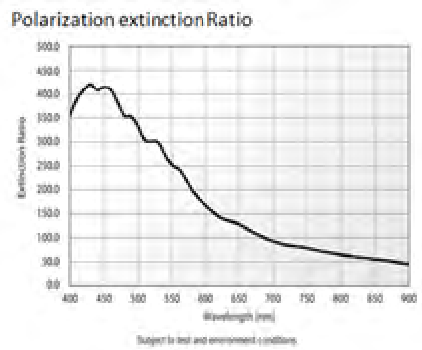
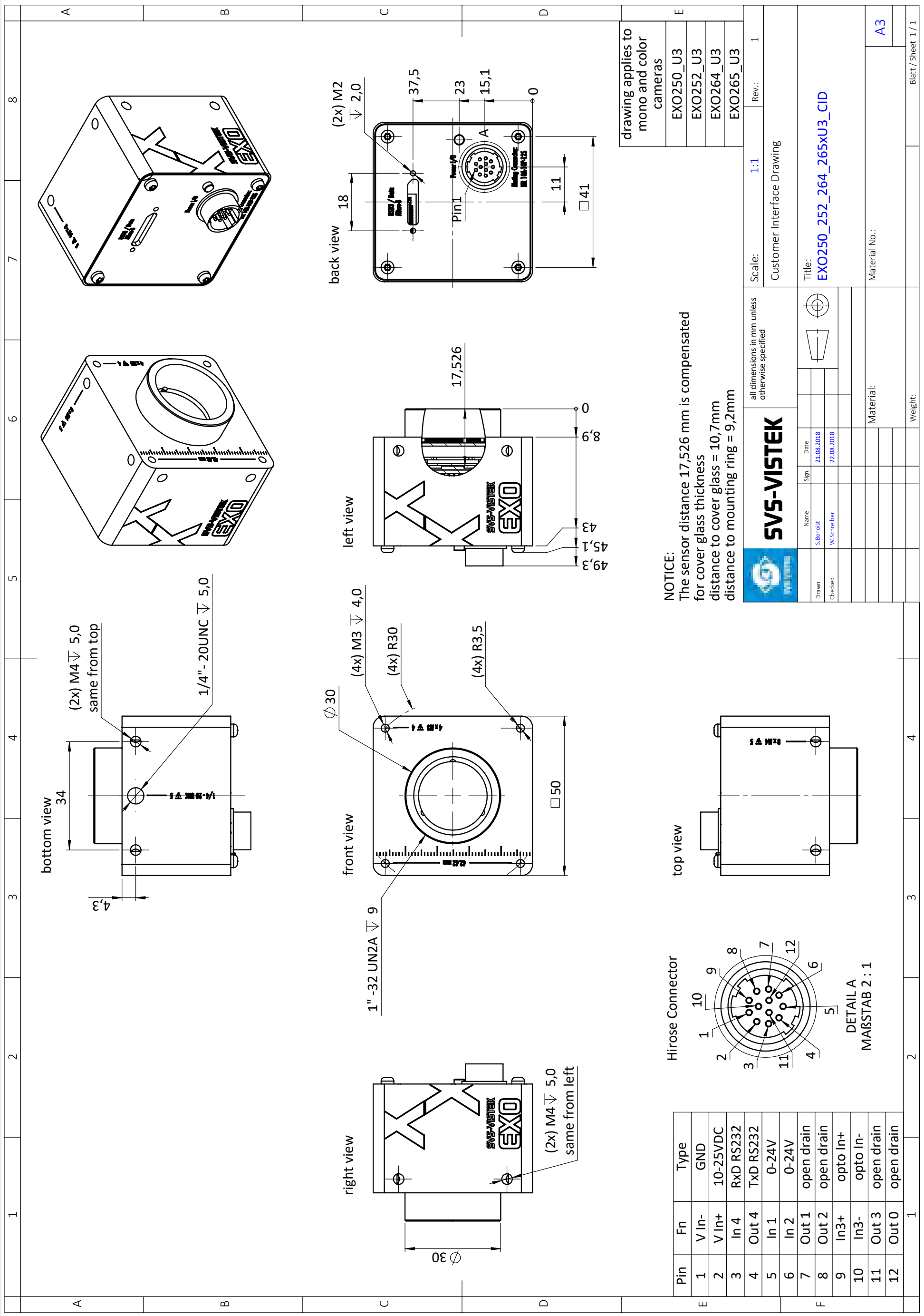


Figure 8: (A) Cell phone LCD, 10x magnification and illuminated with polarized red light. The LCD pixels with red color filter appear brighter. (B) The red filter reflects the light directly; The blue and green filters lets part of the light pass through. Interaction with the underlying optical active media induces a measurable change in the polarization state.

Polarized EXO Series	exo250ZU3	exo250ZGE
Camera		
Resolution (h x v) [px]	2,448 x 2,048	2,448 x 2,048
Frame Rate [fps]	72	23
Chroma	monochrome four directional polarization	monochrome four directional polarization
Interface	USB3 Vision	GigE Vision
Sensor		
Modell	IMX250MZR	IMX250MZR
Producer	SONY	SONY
Sensor Type	Area CMOS	Area CMOS
Shutter	global	global
Sensor size (h x v) [mm]	8.45 x 7.07	8.45 x 7.07
Optical diagonal [mm]	11.01	11.01
Sensor format	2/3"	2/3"
Pixel size [µm²]	3.45	3.45







Pin	Fn	Type
1	V In-	GND
2	V In+	10-25VDC
3	In 4	RxD RS232
4	Out 4	TxD RS232
5	In 1	0-24V
6	In 2	0-24V
7	Out 1	open drain
8	Out 2	open drain
9	In3+	opto In+
10	In3-	opto In-
11	Out 3	open drain
12	Out 0	open drain

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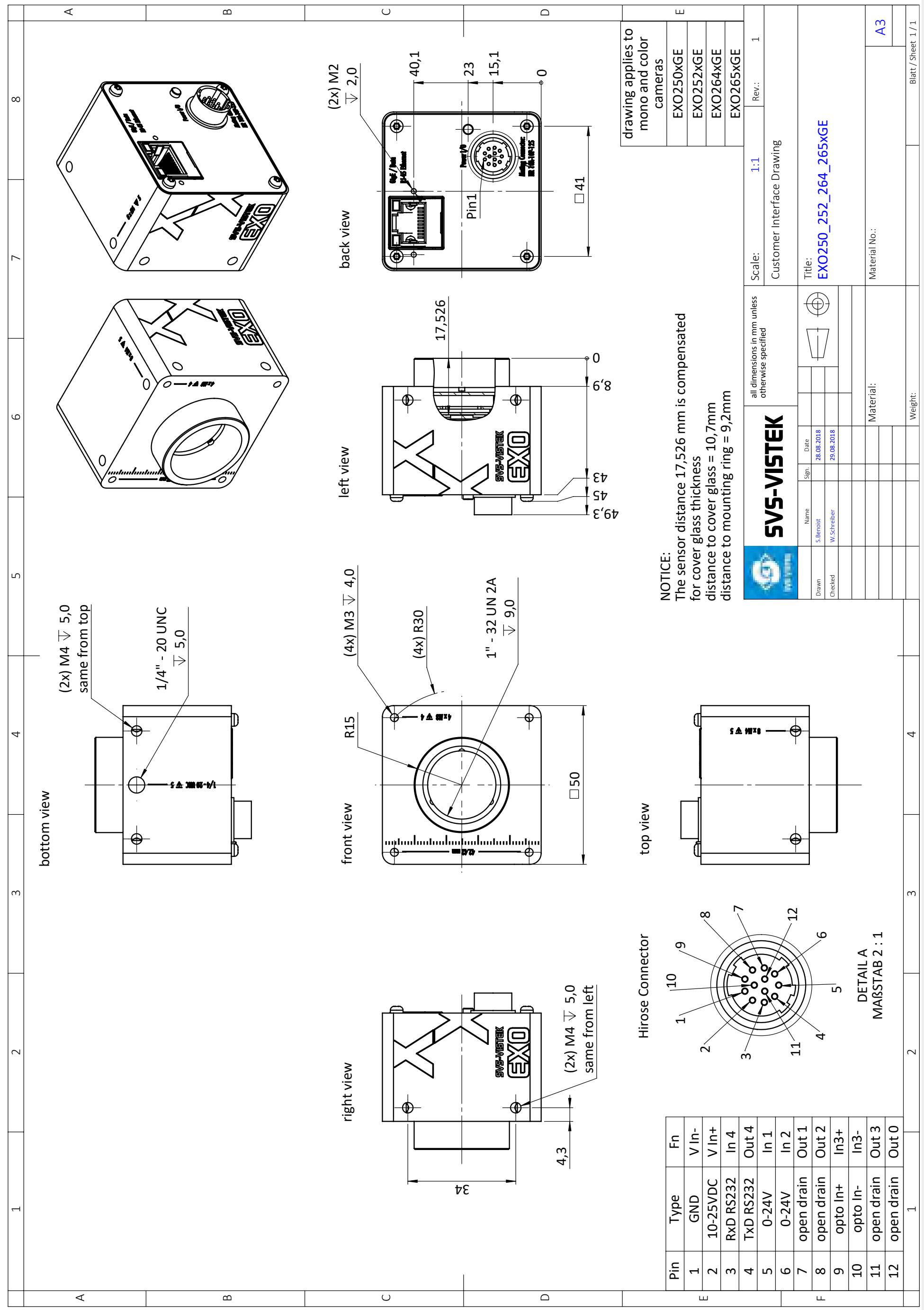
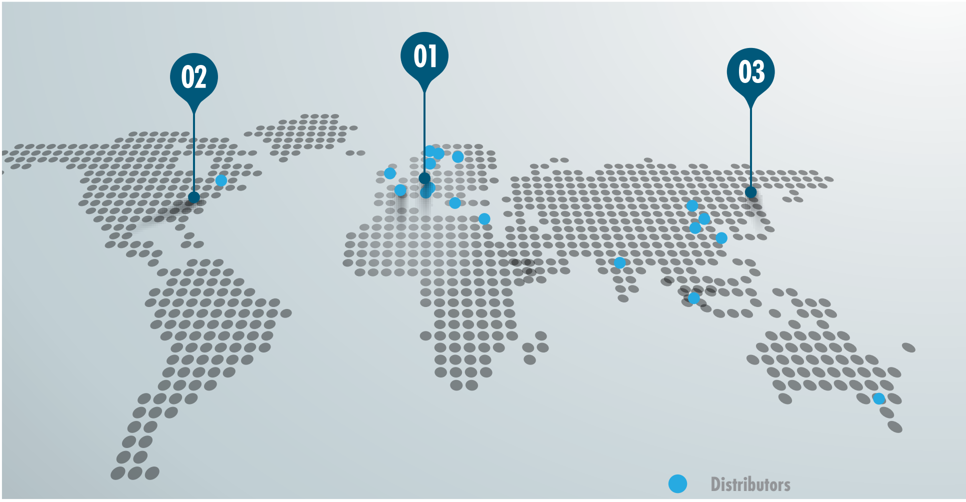


Pin	Type	Fn
1	GND	V In-
2	10-25VDC	V In+
3	RxD RS232	In 4
4	TxD RS232	Out 4
5	0-24V	In 1
6	0-24V	In 2
7	open drain	Out 1
8	open drain	Out 2
9	opto In+	In3+
10	opto In-	In3-
11	open drain	Out 3
12	open drain	Out 0



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