Technical Report

I spy with my little eye

Polarization cameras for industrial applications

Whether mechanical stress in glass, production errors in carbon fiber materials, or quality testing on reflective metal surfaces – imaging with polarized light has been conquering new application areas of industrial image processing. Leading players in this sector are Baumer with its polarization cameras of the CX series and the Fraunhofer Institute for Integrated Circuits IIS with its many years of expertise in the area of polarization imaging.

The effect is stunning – when you look at a water surface on a sunny day, the reflection is so strong that you have to squint. If you put on sunglasses with a polarization filter, however, the reflections suddenly disappear magically and you can look deep into the water. This is why photographers also like to use polarization filters for their lenses to block reflections on water, glass, or metal for high-contrast images. What is useful in everyday life also has great potential for industrial applications. However, this has only become possible within the past few years, because before that there were hardly any cameras or know-how for using polarization imaging. Last year, the IMX250MZR image sensor developed by Sony with polarization filters directly integrated on the sensor was the turning point for the development of suitable polarization cameras such as the CX cameras from Baumer. At the same time, expertise has also been continuously developing, for example, at the Fraunhofer Institute for Integrated Circuits IIS in Erlangen, which has been researching new methods of imaging for more than 20 years and has implemented pilot projects in the area of polarization for many companies. Last year, Baumer and Fraunhofer IIS started exchanging their experiences.

AOP, DOLP, and ADOLP with a single image

The GigE and USB 3.0 polarization cameras from Baumer utilize the polarization characteristics of light. For this purpose, the cameras rely on the 5 megapixel Global Shutter Sensor IMX250MZR from Sony, which features an additional polarization layer. The sensor contains a polarization filter in front of every four neighboring pixels. Each of these filters allows only light with a specific wave direction of 0°, 45°, 90°, or 135° to pass through. Stable evaluation algorithms of the Baumer GAPI software development kit automatically determine the angle of polarization (AOP), the degree of linear polarization (DOLP), or a combination of both (ADOLP, angle and degree of linear polarization) from the raw image data. This way, instead of a complex testing system with various filters or a multi-camera system, all that is required is a single

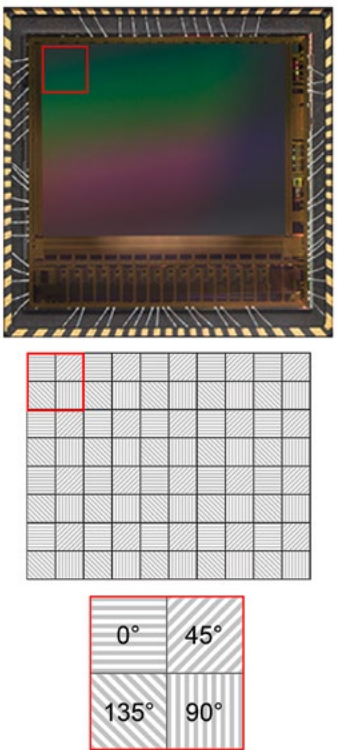

Figure 1

Figure 1: The 5 megapixel global shutter sensor IMX-250MZR from Sony features an additional polarization layer into which four polarization filters are integrated with 0°, 45°, 90°, and 135° in a 2x2 arrangement across the entire pixel array.

camera and a single image, significantly reducing the complexity and the system costs. This allows simple and cost-effective inline solutions in which the user can flexibly determine which information is required for the subsequent image evaluation.

Invisible becomes visible

With the help of polarization cameras, physical material characteristics that are not detected by the human eye become visible and can therefore be evaluated – for example, an oil stain on a metal surface is almost invisible to the eye, but a polarization camera reveals a light-colored circle. Thanks to polarization image processing, such hidden characteristics are uncovered in no time.Imaging with polarized light also enables a range of brand new applications for other industrial areas to help optimize manufacturing processes, reduce production reject, or improve quality. This promises great potential for the glass industry, for example. If glass is under mechanical stress it can break due to agitation, heat, or during cutting. Such invisible stress is already created during the cooling of the glass, especially if it is set in a frame with a different thermal expansion. This is critical, for example, for windows in safety-relevant areas such as the medical or chemical industry. Previously, crossed polarization filters were frequently used in front of and behind the glass to measure the residual stress. If white light shines through it, colored structures become visible as the polarization level of the light is contorted depending on the mechanical stress in the glass, an effect known as stress birefringence. However, since several images must be captured in sequence, this measurement method is not inline-compatible. When a polarization camera is used, a single image provides all the required information to reliably detect stressed glass. An industrial camera offers an additional advantage in this area, as Dr. Schöberl, Head of Business Field Imaging Solutions and Systems at Fraunhofer IIS, explains, "In a glass factory it is hot and dusty, but the

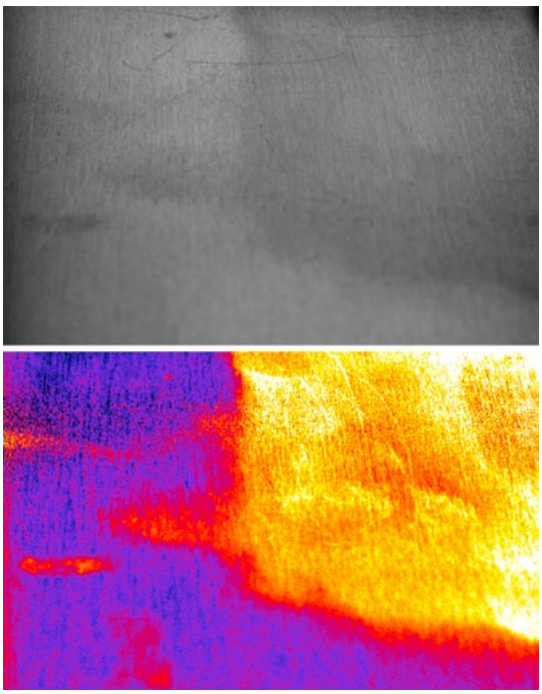

Figure 2

Figure 2: An oil stain on sheet metal (top: intensive image S0) is almost invisible to the eye – polarization cameras make such material characteristics visible (bottom: DOLP polarization level) and thus suitable for evaluation.

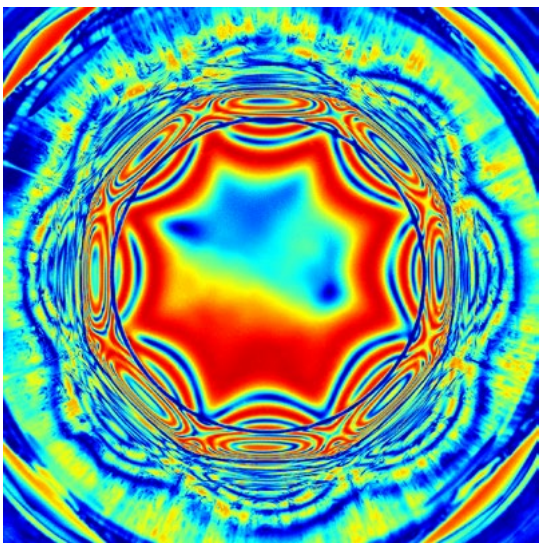

Figure 3

Figure 3: Thanks to polarization cameras, residual stress in the glass becomes visible with a single image (retardation as the measured delay of the light).

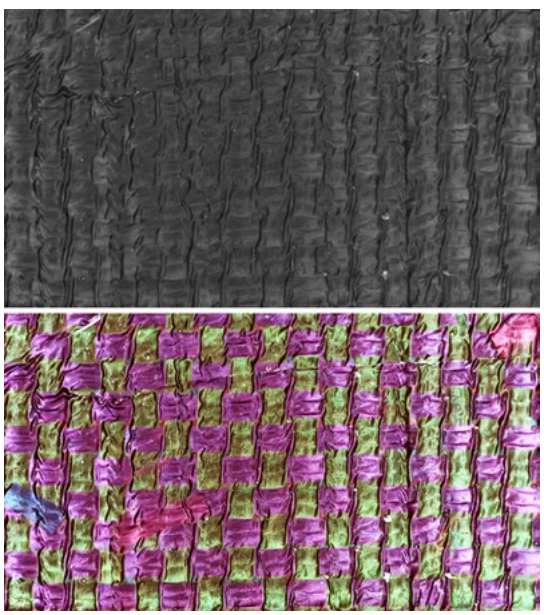

Figure 4

Figure 4: With polarization imaging, the position and deformation of fiber layers of carbon fiber polymers (top: intensity image S0) can be easily tested (bottom: polarization in HSV false color photography).

Figure 5

Figure 5: For the quality testing of reflective surfaces such as foil, polarization cameras score high points and remove glare effects.

Figure 6

Figure 6: The polarization cameras of the CX series are suitable for quality control in glass production, the manufacturing of carbon fiber materials, or the surface inspection of reflective materials.

measuring system must function absolutely reliably." Robust polarization cameras like the ones offered by Baumer can offer decisive advantages in this regard. Imaging with polarized light is also interesting for the quality testing of carbon-fiber reinforced plastics (CFRP), which are used in the automotive or aircraft industry. To the human eye, carbon fiber material appears dark gray, but a polarization camera recognizes that the polarization angle of the reflected light varies and depends on the direction of the fibers. In calculated images, the fiber direction is depicted in color. This way, errors in the fiber course that are not detected with the naked eye but have a decisive effect on the stability of the material are reliably detected. Thanks to polarization calibration at the factory, the CX polarization cameras can achieve an angular resolution of 1°, to reliably detect even the finest deviations in the fiber direction. Polarization cameras also score extra points when it comes to inspecting reflecting or glossy surfaces such as metal or foil. Selecting a polarization direction effectively reduces glaring effects, for example, to better detect scratches or read codes more reliably, without making the image darker as a whole.

Not a universal remedy

Within the past few years, Fraunhofer IIS has established a high profile in the area of polarization imaging. "Many users come to us with a specific problem and ask if we can resolve it with our technology. But there are limits," says Schöberl. For example, when it comes to black stained glass or laminated glass. "We look at each case individually and if we consider that there is potential for success, we will test it on a sample part." Therefore, while imaging with polarization cameras is an important complementary factor for quality assurance, it is not a universal remedy. This is why a comprehensive approach is crucial to the success of all participants.

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