Beyond visible: the importance of polarization in machine vision

OPTO ENGINEERING

INTRODUCTION

Polarization refers to a characteristic of transverse waves that defines the geometric alignment of their oscillations. In a transverse wave, such as light, the direction of the oscillation is perpendicular to the direction of motion of the wave. The alignment of these oscillations depends on the interactions of the wave itself with the surface that reflects it.

In this article we will look at some general aspects of polarization and then focus on how it can be exploited to solve different types of machine vision tasks that would otherwise be very difficult if not impossible.

Definition and main types of polarization

An electromagnetic wave, such as light, is composed of a synchronized oscillation of electric and magnetic fields, always oriented perpendicular to each other. In the context of electromagnetic waves, "polarization" conventionally refers to the orientation of the electric field.

In linear polarization, both electric and magnetic fields oscillate in a single, unchanging direction. In circular or elliptical polarization, these fields rotate at a consistent rate within a plane as the wave propagates, either in a clockwise (right-hand) or counterclockwise (left-hand) direction.

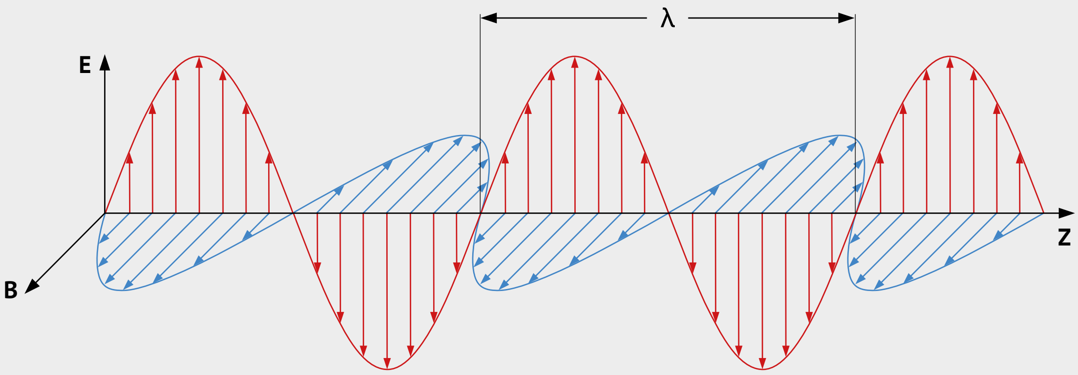

Figure 1: Linear polarization: the electric field E (in red) oscillates along only one direction (vertical). The magnetic field B (blue) is always perpendicular to the electric field.

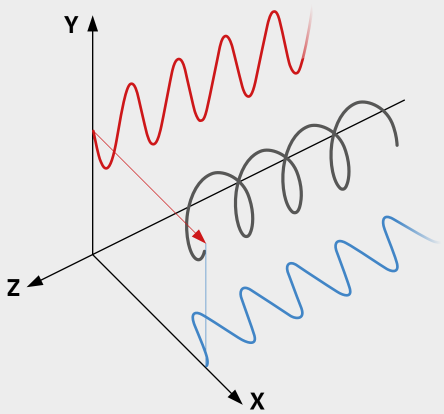

Figure 2: Circular Polarization: In this case, the red sine wave and the blue sine wave indicate the two projections of the electric field in their respective X and Y axes. Since the two waves are phased by 90 degrees, the resulting total electric field of the electromagnetic wave (represented by the arrow) performs a circular spiral.

Light polarization and interaction with reflecting surfaces

Typically, most optical materials do not alter the polarization of light. However, certain materials, characterized by properties like birefringence, dichroism, or optical activity, impact light differently based on its polarization. Some of these materials are employed in the production of polarizing filters.

Additionally, light undergoes partial polarization when it reflects from a surface. The degree of polarization of the reflected lights depends on the incidence angle.

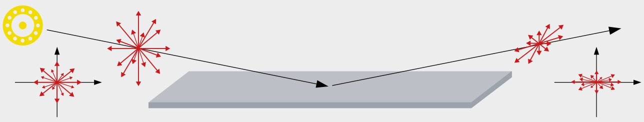

Figure 3: Partial polarization upon reflection.

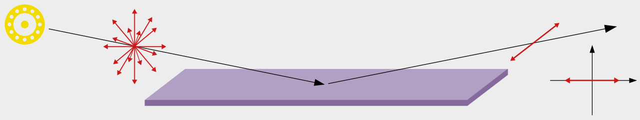

Figure 4: Complete light polarization at Brewster angle.

In *Figure 3* we can see comprising multiple wave patterns hitting a reflective surface. These waves typically exhibit a statistical distribution in terms of both intensity and oscillation orientations, which characterizes them as "unpolarized light." When light undergoes reflection at the interface of a dielectric material, a fascinating transformation occurs. The reflectivity of the polarization component aligned with the surface normal varies from the polarization component perpendicular to it. Consequently, the resulting polarization ceases to be unpolarized and assumes partial polarization.

In specific cases determined by the material's properties, a particular angle, known as the Brewster angle, plays a pivotal role. At this angle, only the polarization component parallel to the surface normal is reflected, marking an intriguing aspect of light behavior. *Figure 4* shows this peculiar phenomenon.

Polarization techniques

A polarizing filter can be placed in front of the camera lens in order to manage reflections or suppress glare from the surface of objects. Since reflections (and natural light) tend to be at least partially linearly-polarized, a linear polarizer can be used to change the balance of the light in the picture.

In machine vision, typically three directions of polarization are employed (0°, 90° and 45°), therefore three different polarizing filters are required. These can be mounted on three different cameras, or they can be alternating in front of a single cameras. A far simpler and cheaper alternative, however, is the new Sony Polarsens™ sensors that Opto Engineering's ITALA® cameras also integrate.

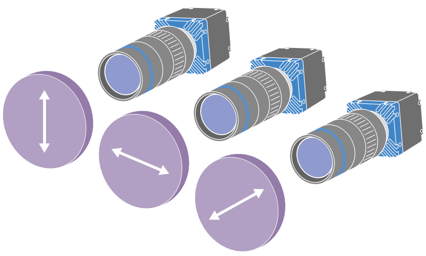

Figure 5: Traditional solution featuring three cameras with different polarization filters.

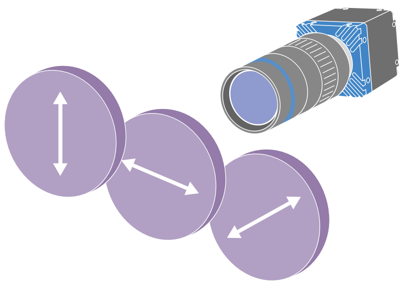

Figure 6: Another traditional solution featuring three filters that rotate in front of a camera.

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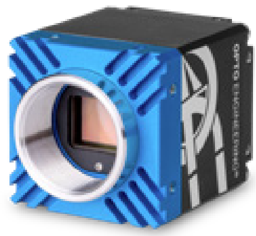

Figure 7: Preferred solution featuring ITALA® cameras integrating Sony Polarsens™

Sony Polarsens™ technology

Sony Polarsens™ image sensors feature a multi-directional polarizer that is integrated directly onto the photodiode of the image sensor chip, referred to as an "On-Chip Polarizer." These sensors not only capture standard brightness and color information but also have the capability to record polarization data that traditional image sensors cannot detect.
These sensors are equipped with global shutter technology that enables high image quality without distortion in the focal plane as is the case with rolling shutter sensors. They also have features such as ROI mode and trigger mode to best optimize image acquisition.

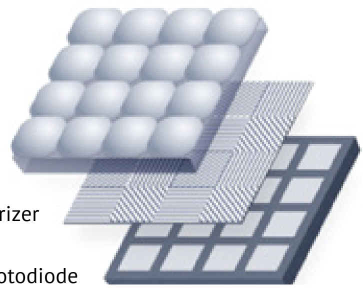

Figure 8: Sony Polarsens™ image sensors structure.

Typical applications of polarized sensors

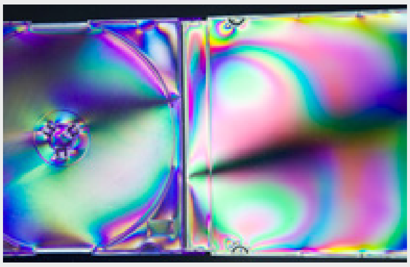

Figure 9: Analysis of stress induced by manufacturing processes.

As polarized light passes through transparent materials, the incident angle of polarization undergoes alteration as it interacts with various stress regions within the object.
By associating distinct colors with specific polarization angles, it becomes possible to visually represent defects and stress zones.

Figure 10: Polarizer placed in front of the camera to reduce reflections and improve visiona.

Employing polarizers can effectively minimize undesirable reflections, leading to enhanced imaging performance. Consider scenarios where glossy or metallic materials are being examined; such situations often give rise to "hot spots." These hot spots correspond to points on the object surface that generate intense glare. In these cases, placing a polarizer in front of the camera can significantly reduce unwanted reflections to improve vision.

Figure 11: Reading embossed lettering. On the right, an image taken with unpolarized light, while on the left, a study in polarization is conducted.

Through light polarization, contrast can be increased, allowing elements that would otherwise be difficult to detect, such as embossed lettering, to be highlighted.

Figure 12: On the left, the blister pack with the tablets is illuminated with non-polarized light. On the right, the illumination is done with polarized light, and a subsequent polarizer is placed in front of the camera. The difference in polarization reflected (between the aluminum of the container and the tablet) significantly increases the contrast.

The variation in the degree of polarization tilt observed in the light reflected from various surfaces offers the capability to analyze the contents within specific containers.
To illustrate, in the case of medical blister packs, disparities in the polarization of reflected light, either from the tablet or the aluminum, enable the verification of whether the tablet is present or absent within the container's compartment.

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