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LIGHT IDEAS #3: Do White Bears Have Polar Eyes?

Suppose you need to detect diffuse defects against a shiny background, particularly an irregular one, or vice versa. Or what if good and bad parts have similar grey levels?

Figure 1 shows two different metal parts viewed from above and illuminated with a coaxial ring fiber optic. The left part has a tumbling stone stuck in it. The right part has streaks of paint. You can see the stone, though in fact it has about the same grey level as much of the surrounding metal. You might be able to see the paint streaks, but just barely. They are mostly overwhelmed by glare at the edges.

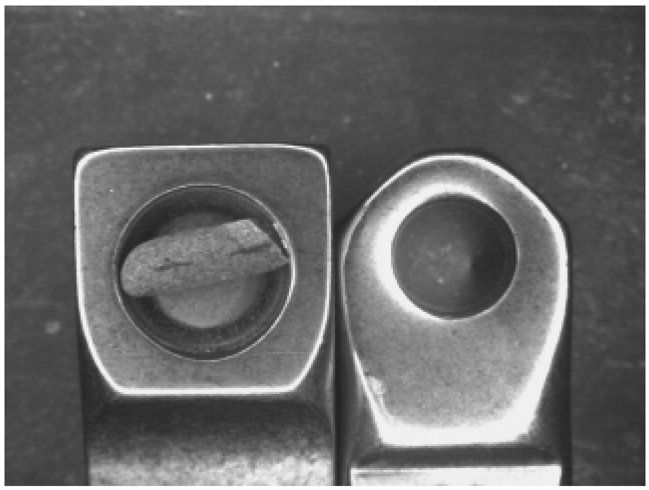

Figure 1 – Standard Illumination

Figure 2 shows the same two parts, but with a linear polarizer in front of the output portion of the ring fiber optic, and a crossed linear polarizer in front of the camera lens. There has been no image processing done in either case.

Figure 2 – Contrast Enhanced By Polarization

Pretty good contrast enhancement, isn't it? Also notice that the illumination of the metal is much more uniform in the second case. Figure 3 shows the configuration schematically.

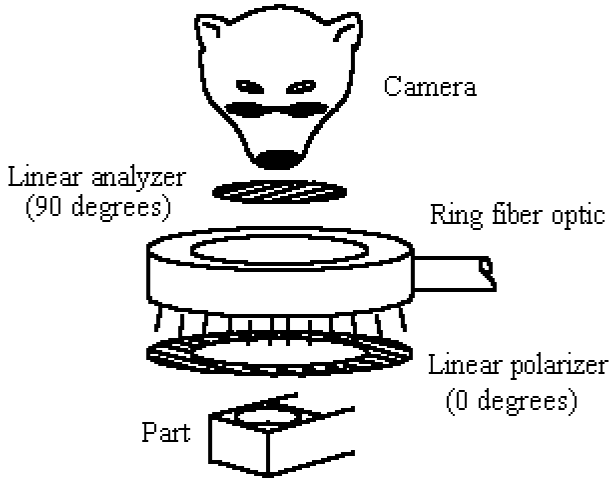

Figure 3

This illustrates one of the many ways that polarization techniques and materials can significantly improve the optical front end of a vision system. In fact, these methods are some of the most powerful tools in the optics toolbox.

But how do they work?

Light can be described as a transverse electromagnetic wave – it wiggles like a rope when you shake one end. If randomly polarized light (sometimes called un-polarized) is traveling in the z-direction, the planes containing the wiggles or vibrations are, on average, equally distributed in all x- and y-directions. Also, on average, the vibrations have the same amplitude in each direction. If the plane of vibration is only in one direction, the light is said to be linearly polarized. Figure 4 illustrates these two cases.

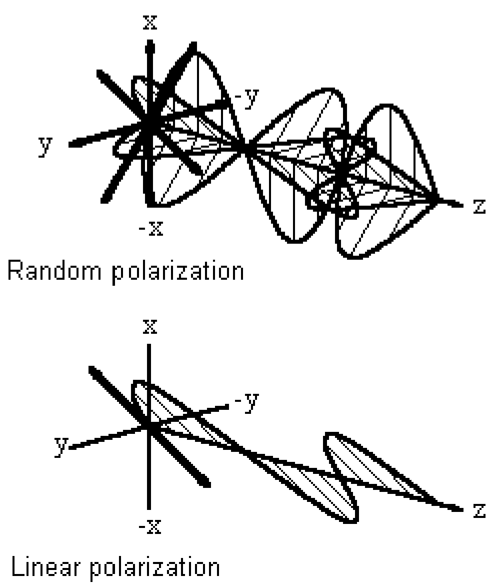

Figure 4

The case for random polarization actually looks much more complicated than what is shown here, but you get the idea. Notice that we've also drawn some arrows or vectors in the x-y plane. This is a short hand way of indicating the vibration direction of whatever type of light we're talking about.

Okay, so light is a transverse wave that has polarization. Big deal. How does this explain the differences between Figure 1 and Figure 2? First we need a few more pieces for the puzzle.

There are optical devices that can convert one type of polarized light to another. (We've mentioned linear. There are others that will be discussed in a later issue.) One such device is called a linear polarizer. There are different ways of doing this, but the important point is that the device allows only light vibrating parallel to its polarization axis to pass through.

The second point is that when light of any polarization strikes a smooth and shiny (specular) surface at normal (perpendicular) incidence, the reflected light will maintain its state. There may be a phase change in the light wave, but that's not important for this discussion. Linearly polarized light will still be linearly polarized, and vibrating in the same direction. The final point is that when light of any polarization strikes a rough, scattering surface, such as some paints, stones, abraded surfaces, paper, etc., much of the reflected light becomes randomly polarized.

By the way, notice that normal incidence was specified for maintaining polarization state upon reflection from a specular surface. If the incidence angle is off-normal, other effects can occur that change the polarization state. Often, however, the change is small and you can still greatly benefit from the techniques described here.

Okay, now we're ready to explain the contrast enhancement that we used for opening this show. Suppose randomly polarized light strikes the smooth metal part as well as the rough stone and the rough paint streaks. Randomly polarized light will be reflected in all cases. Suppose, however, that linearly polarized light is used. The metal will reflect linearly polarized light, while the other surfaces will still reflect mostly randomly polarized light. Finally, suppose you place a linear polarizer in front of the lens of the camera that is viewing these parts. Sometimes this is called an analyzer. You also orient its polarization axis so that it is perpendicular to the vibration direction of the original linearly polarized light. Figure 5 shows this situation.

It's clear that the light which is reflected from the smooth metal will be blocked by the analyzer and it will appear quite dark. But the light reflected from the rough surfaces, now randomly polarized, will have some component that happens to vibrate in the direction that allows it to pass through the analyzer. Thus, the rough surfaces appear bright compared to the metal.

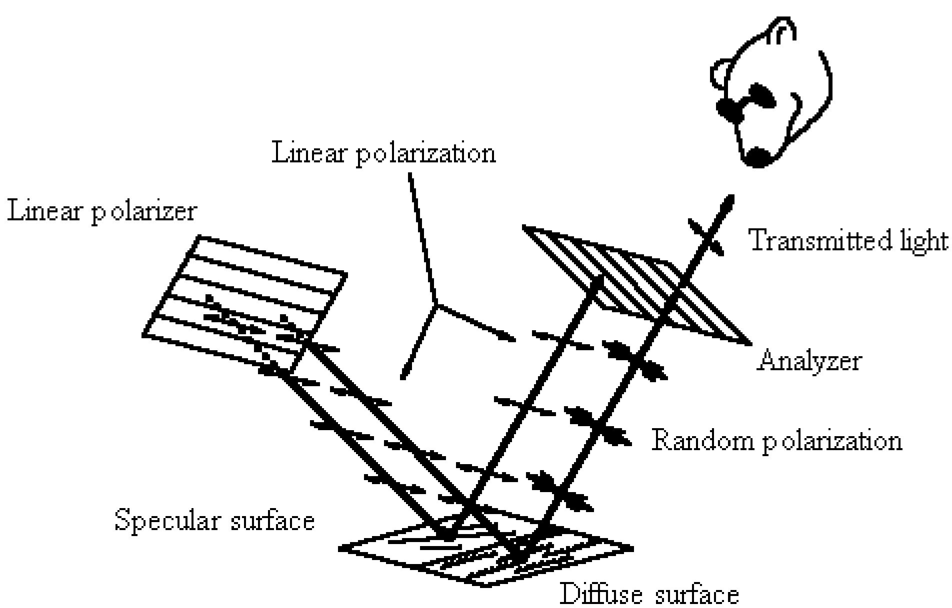

Figure 5

There are, of course, many other ways of using polarization to enhance contrast or eliminate unwanted features such as bright reflections. Likewise, as mentioned before, there are many ways of producing polarized light. One of the most practical is to use sheet polarizer. It's pretty cheap and easily used in optical systems that don't require high polarization purity.

Even if you don't need very pure polarization, there's something to watch out for when using sheet material. Different types will have different spectral ranges over which they operate well, but none provide excellent performance over a very broad range. The use of spectral filters with sheet polarizer is often recommended, particularly if there is a high infrared content to the light such as with incandescent or arc sources. You should at least use an IR cut-off filter if your detector isn't already equipped with one. Otherwise, the IR can blast right through the polarizer, creating very high unwanted signals for your camera … or your bear!