



USING LIGHTING TO OPTIMIZE CAMERA PERFORMANCE

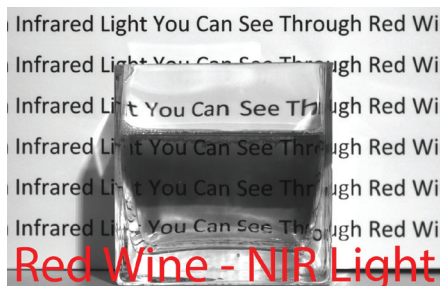
Capturing Clear Images and Highlighting Details with the Right Light Source





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USING LIGHTING TO OPTIMIZE CAMERA VISION PERFORMANCE



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INTRODUCTION

How light works can be a complicated subject. One of the biggest rules of thumb in imaging is that there can never be too much light. However, a common problem is finding enough light to clearly image a subject. Utilizing light sources in an efficient and deliberate manner can address this problem by reducing the amount of light required to image a particular subject and help to highlight details or defects.

This paper will cover general lighting theory, explore different light sources, and how to best use lighting equipment for practical applications. For example, near infrared (NIR) inspection and contrast enhancement for computer vision can be achieved using filters. However, the use of filters will reduce the amount of light reaching the sensor, requiring a more sensitive camera. When using specific light that is transmitted by filters, the reduction of other light allows for clearer images.

LIGHTING THEORY

When light interacts with a target, there are four possible outcomes: it is reflected, absorbed, scattered, or refracted by the object. However, these outcomes are not mutually exclusive and a combination of these individual outcomes is possible – especially at different wavelengths.

Most lighting challenges involve mitigating scattered and reflected light. Scattered light is typically what vision systems prefer because it produces uniform light intensity from the surface of an object, whereas reflected light creates harsh “hot spots” making it difficult to capture an image.

Depending on which wavelengths are absorbed and which are reflected will determine what color is visible. Controlling which wavelengths are emitted by a light source can help make details easier to discern by enhancing contrast, which will be expanded upon later in this paper.

Refraction refers to how light travels through a medium such as water however, that is outside the scope of this paper.

Reflection and Scattering

Reflection and scattering can occur simultaneously on the same target. The direction and intensity of a light source will determine how much light will get reflected / scattered.



Figure 1 - Low Angle Reflection Off Liquid

Specular flat reflection results in minimal distortion as seen in Figure 1. Materials such as mirrors, highly polished metal surfaces, and liquids at low angles can produce specular flat reflection. Proper lighting position is required when using such materials so that light is not directly reflected into the camera's lens.



Figure 2 - Unevenly Lit Machined Metal



Specular multi-faceted reflection can become a challenge on uneven reflective surfaces. The roughness of the target results in light being partially scattered, yet at a high enough intensity reflected light can cause glare and diminish contrast at the target surface. This type of reflection is common with machined metals, fresh solder, and rolled metals.

Lastly, amorphous surfaces completely scatter incident light in all directions, producing a diffuse reflection. Materials with this type of light scattering ability, for instance, white paper, fine powders such as flour or icing sugar, and ceramics are often used to illuminate other objects. By pointing a concentrated light on the surface of the material a diffuse reflection can evenly light a subject.



Figure 3 – Amorphous Icing Sugar

Brightfield and Darkfield Illumination

Brightfield and darkfield illumination are the two distinct methods for forward facing lighting. These methods can be explained based on the angle of illumination.

Brightfield illumination is defined by having the light source within the reflection cone of the camera's field of view (FoV). The blue cone seen in Figure 4 defines the camera's FoV. Light that is positioned in front of the target is reflected back into the camera, while the FoV is seen by the inner and outer angle of reflection. In two dimensional models, this is also referred to as the illumination "W" due to the inner and outer angles creating a "W" boundary.

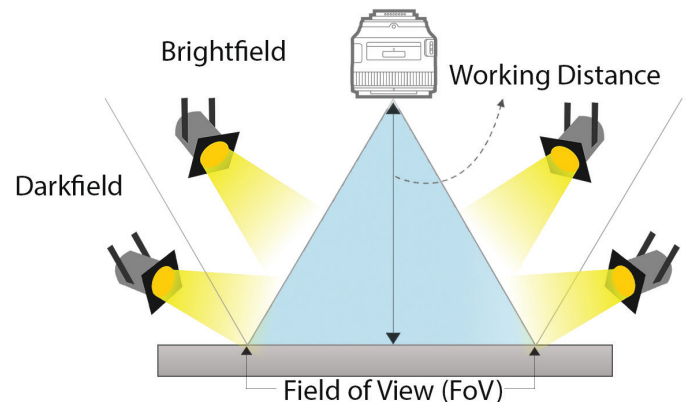


Figure 4 - Amorphous Icing Sugar

Reflected light that has an incident angle outside this "W" boundary is referred to as darkfield illumination. In Figure 4 light can be seen at a much lower angle to the target, creating high contrast due to most light being reflected away from the camera lens. To better see defects or surface changes, darkfield illumination is normally preferred, while brightfield illumination provides even lighting distribution.

Backlight Illumination

Lighting a target from behind is typically done using a uniform light source facing the camera. When backlight illumination is used, solid objects will appear black and the background white, allowing a clear inspection of the target's edges. Examples where backlight illumination is best used include object outline verification, and metal-shaving detection in machined parts.



Translucent objects benefit from uniform illuminations due to reflections being directed back towards the light source. The image captured of the target is the result of transmitted light that passes through the target itself, making it an excellent choice for reflective and translucent plastics.

TYPES OF LIGHTING

Recent LED lighting innovation has been a disrupting factor in the lighting industry, allowing for new configurations and form factors. This section will cover a small subset of lighting solutions to provide a general idea of what is available. Lighting configurations should be tested with actual equipment to ensure proper system reliability before large scale deployment. Where possible, all external light sources should be reduced or removed from the area, allowing only the light sources chosen to interact with the imaging system.

Area Light

Area lights are what most think of in terms of general lighting. They illuminate an area with a relatively even distribution of light, provided the source is far enough away from the subject to not create “hot spots.” With careful placement, one to two area lights are often sufficient for general imaging purposes.

Ring Light

Ring lights are essential for illuminating specular (highly reflective) surfaces because they help to eliminate reflections and create shadow-less images. They are placed directly in front of the camera with the lens looking through the opening in the center of the ring. This way, light falls on the target from all directions around the lens and reduces the appearance of shadows.



Figure 5 - Ring Light Mounted on a Camera Lens

Dome Light

Dome lights are ideal for illuminating highly specular and textured surfaces such as ball bearings, metallic cylinders, and machined metals. The camera lens is positioned to face the opening in the dome where the subject of interest is visible. Light emitted from a source is reflected from the inside surface, onto the target, and then reflected back through the opening in the dome towards the camera, as seen in Figure 6. For this reason it is important that the inside of a dome light be of a material that scatters light and has little to no specular reflections.

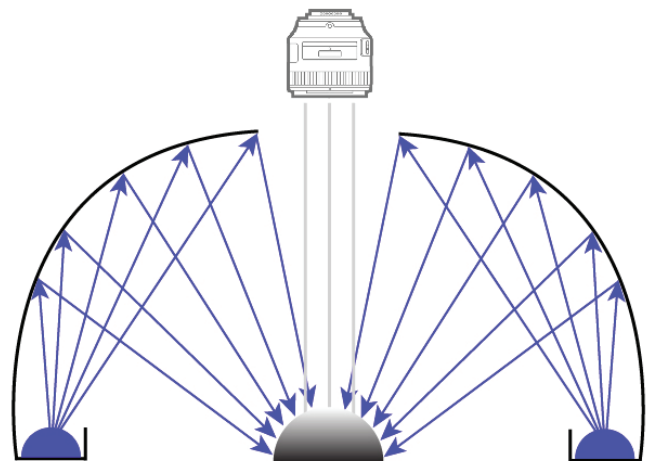


Figure 6 – Dome light covering an object being illuminated inside and photographed through an opening on the top



Structured Light

Structured light is typically used for three dimensional object mapping. It consists of illuminating an object with one or many laser lines, as seen in Figure 7. By looking at the patterns of light and the deviation in the laser line(s), the object's height and profile can be determined.



Figure 7 - Various Structured Lights

Colored Light

Adding color or more accurately, using specific wavelengths, with any of the previously mentioned lighting types (except for structured light) can help enhance details or increase contrast, depending on the application. Using a narrower portion of the visible spectrum will selectively illuminate certain objects in the scene without generating reflections from less important areas in the same scene.

PRACTICAL LIGHTING EXAMPLES

The following section covers a few practical examples where specific properties of light can be used to enhance details of an image. In these examples, conventional white light would be unable to produce the same results.

Enhancing Vision with Near Infrared Light

Infrared lighting can be used for a number of imaging solutions to enhance details that are not visible to the human eye. Since most imaging systems have some sensitivity in the NIR wavelengths (750-1200 nm) they are able to see visual information that our eyes are unable to process. The following two scenarios will explore how infrared light is used to visualize practical applications.

NIR Light Used to See Through Opaque Liquids

Many liquids freely pass longer wavelengths of infrared light, which allows for some visibility through a liquid with the right equipment. Using a monochrome Teledyne Lumenera Lt345R camera and an infrared light source, it is possible to see through a variety of opaque liquids such as red wine and cola.

The example shown in Figure 8 depicts a glass container with text printed in the background. In the first image, the container is empty and the text can be read with some distortion through the glass. In the second image, the container is filled with red wine. As the inside of the glass container measures four inches by four inches, the camera is unable to see the text behind the glass under white light. In the third image, using NIR light, the camera can see through four inches of red wine and make out the text behind the glass.

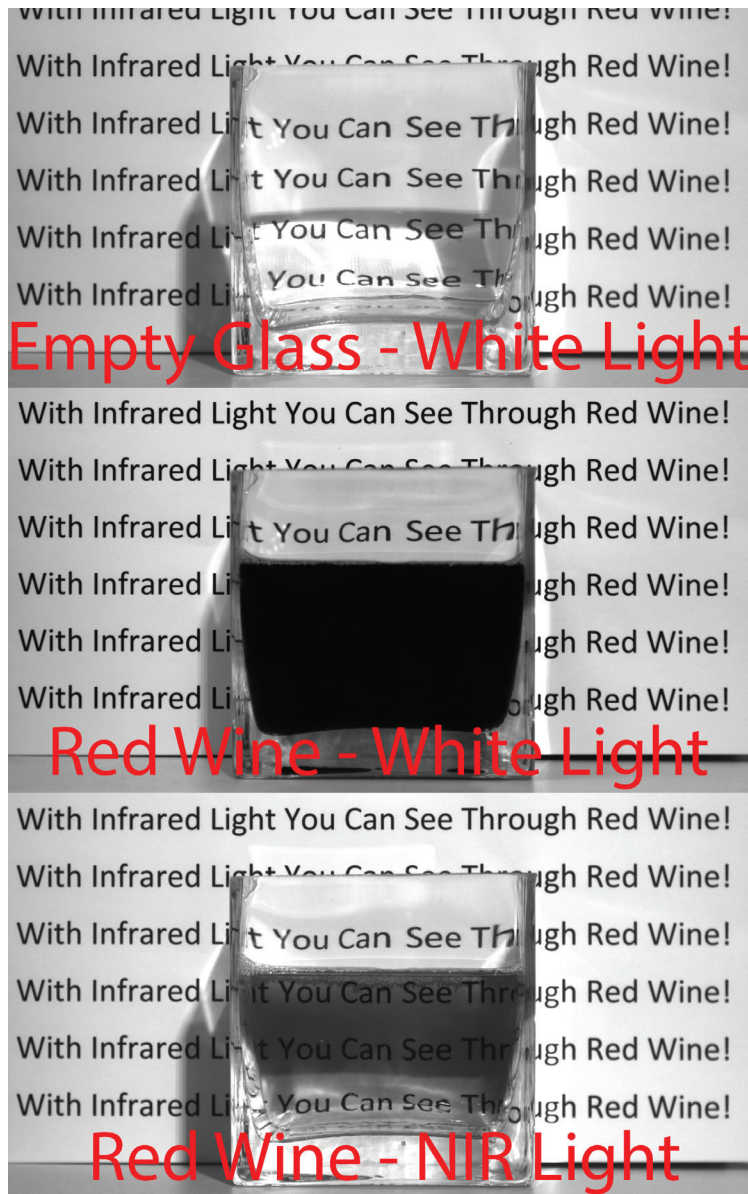


Figure 8 - Experiment Illustrating Translucent Red Wine with NIR Light

In the second example, in Figure 9, a glass was filled with cola and placed a spring and metal washer inside the glass to simulate an inspection application. Normally NIR light would be used to ensure that no foreign objects are inside containers with opaque liquids before they are sent to a customer. This simple setup demonstrates how easily the system would be able to see the problem within the right glass.

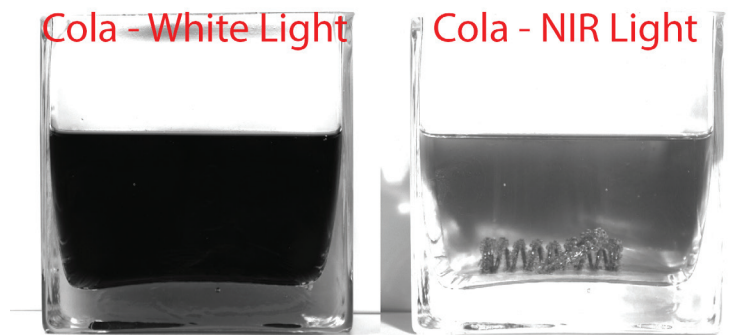


Figure 9 - Foreign Object Detection in Cola with NIR Light

NIR Light to Enhance Buried PCB Traces

When inspecting areas covered by a solder mask and / or by silkscreened letters on a printed circuit board (PCB), it is far more efficient to use NIR lighting because the wavelengths easily penetrate the thin coatings, but reflect off of the buried copper traces.

As shown in Figure 10, the top image is a portion of a PCB under visible light and the bottom image is under NIR light. In the upper image, the copper traces going from the left plated pads to the top pads are obscured by the solder mask and silkscreened "TP 10" lettering. When using NIR light in the lower image, the silk screened lettering is nearly invisible. The copper is of consistent intensity through the length of the trace and at the exposed pads. This illustrates that the solder mask has no visible effects on the buried copper traces under NIR light.

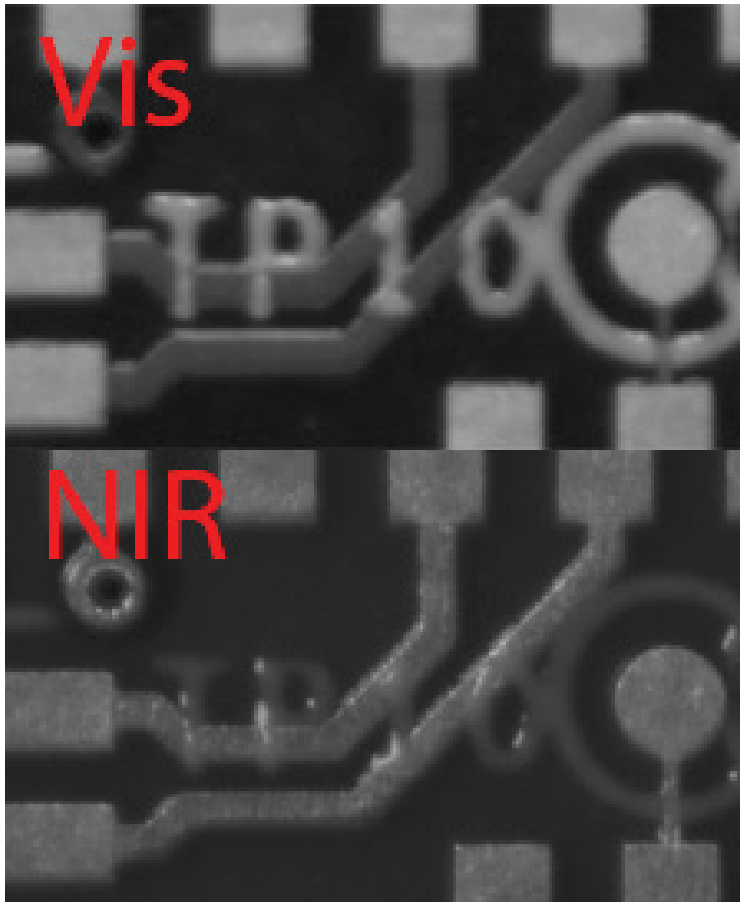


Figure 10 - Inspection of Buried Trace on PCB with NIR Light

Enhancing Contrast with Colored Light

Using colored lighting can increase contrast in computer vision inspection. Since most vision systems use monochrome cameras, colored lights can be used to “mute” background colors and put emphasis on the details the system is trying to see.

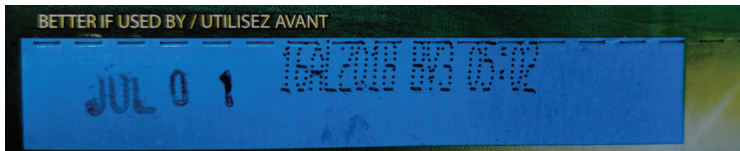


Figure 11 - Two Different Date Stamps on a Blue Background in Color

This can be seen with two date stamps in the following example. Figure 11 shows the color image of both stamps. The left stamp uses red ink and the right stamp uses black ink, both on a blue background. The following image in Figure 12 shows the same label using a monochrome Teledyne Lumenera Lt345R camera. It also illustrates the difference in pixel value between the lettering (the dips in the graph shown in the lower part of Figure 12) and the background (the peaks) across the yellow line in the image.



Figure 12 - Contrast Analysis of Date Stamps Under White Light

In Figure 12, when using a white light the grayscale pixel values dip by around 15 for first letter, J. Using blue light generates a brighter background and helps increase the contrast with the lettering. This is seen in Figure 13 by the 40 point dip representing the same letter. This is because the red ink in the lettering absorbs all the blue light while the background reflects a large amount of it. In the version using white light, the red ink reflects the red components of the white light while the background reflects the blue components. This greatly reduces the contrast ratio which is why targeting the subject with specific wavelengths is highly beneficial for machine vision applications.

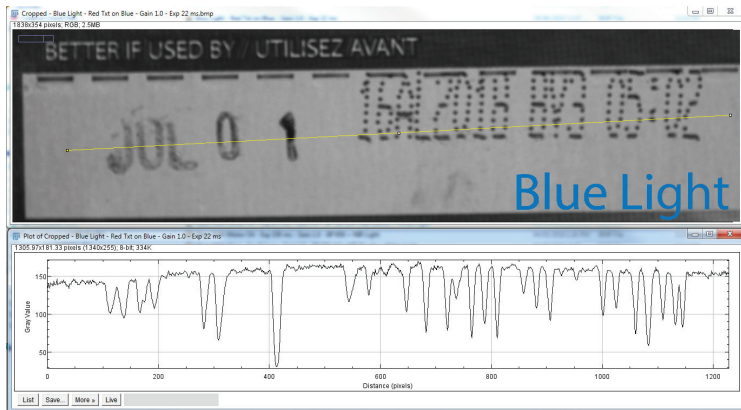


Figure 13 - Contrast Analysis of Date Stamps Under Blue Light

Polarized Light and Polarized Filters

Polarizing a light source and combining it with a polarized filter helps with defect inspection as seen in the following Figures 14 and 15. In this example, a polarizing filter is placed on the backlit light source as well as on the camera's lens. A plastic ruler is then placed on the polarized light source to observe the defects. When the polarizing filter on the camera is rotated to align with the polarizing filter on the light source, the light transmitted through the ruler shows that scratches are present on the plastic.

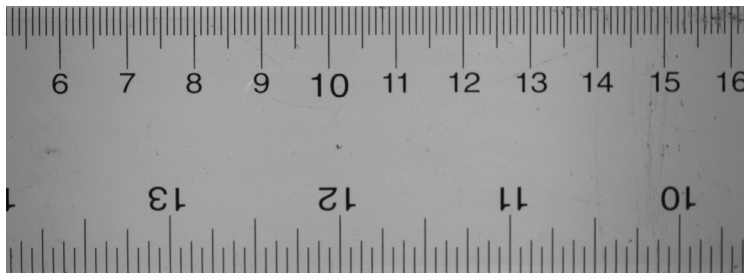


Figure 14 - Defect Detection of Plastic Ruler Using Unpolarized White Backlight

Rotating the filter by 90° will block the polarized light from entering the camera lens. However, defects in plastics tend to change the orientation of polarized light. This principle allows the camera to easily see the defects since they are transmitted by the second polarized filter, as can be seen in Figure 15. The defects appear as white marks as the light's polarization is changed further by the scratch.

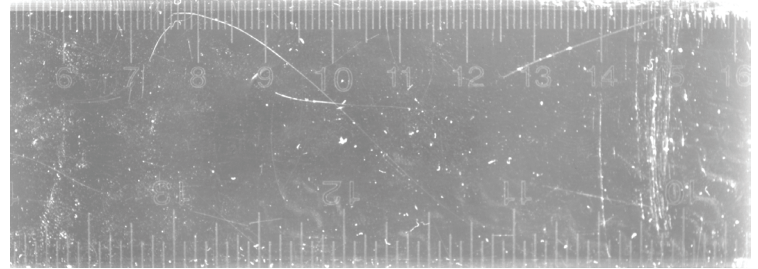


Figure 15 - Defect Detection of Plastic Ruler Using Polarized White Backlight

CONCLUSION

An image can be drastically altered by the type of light source used and the way in which it illuminates the subject of interest. When working with specific material it is important to consider how light will reflect off of it, but also the angle at which light will make contact with the subject to properly highlight the details. Whether it is a matter of inspecting solid surfaces with polarized light or surfaces through liquids using NIR light, using proper lighting is key.