A Practical Guide to Machine Vision Lighting - Part I

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Overview

It is well understood that the quality and appropriateness of lighting are critical aspects for creating a robust and timely vision inspection. In addition to an understanding of illumination types, techniques, geometry, filtering, sensor characteristics, and color, a thorough analysis of the inspection environment, including sample presentation and sample-light interactions provide a foundation upon which to design an effective vision lighting solution. It is suggested that designing and following a rigorous lighting analysis sequence will provide a consistent, and robust environment, thereby maximizing time, effort, and resources – items better used in other critical aspects of vision system design, testing, and implementation.

This tutorial is the first document in a three-part series written by Daryl Martin, from Advanced Illumination, that demonstrates machine vision lighting concepts and theories. Refer to A Practical Guide to Machine Vision Lighting – Part II and A Practical Guide to Machine Vision Lighting – Part III for further discussion of machine vision lighting design.

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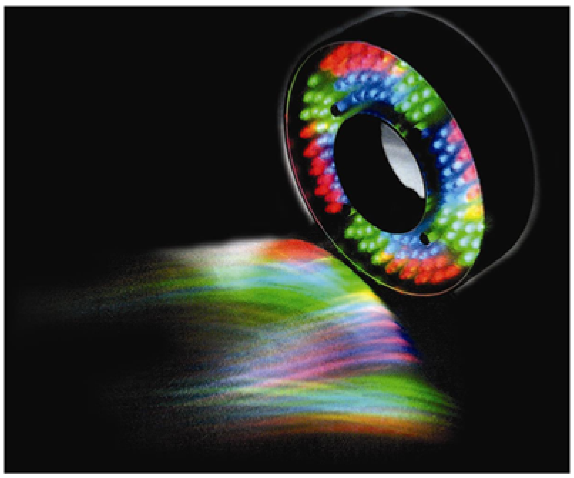
1. Introduction

This document is part of the
Machine Vision Fundamentals Series

Perhaps no other aspect of vision system design and implementation has consistently caused more delays, cost-overruns, and general consternation than lighting. Historically, lighting often was the last aspect specified, developed, and or funded, if at all. This approach was not entirely unwarranted, as until recently there was no real vision-specific lighting available on the market, meaning lighting solutions typically consisted of standard incandescent or fluorescent consumer products, with various amounts of ambient contribution.



The objective of these articles, rather than to dwell on theoretical treatments, is to present a “Standard Method for Developing Sample Appropriate Lighting”. We will accomplish this goal by detailing relevant aspects, in a practical framework, with examples, where applicable, from the following 3 areas:

1. Knowledge of:
   - Lighting types, and application advantages and disadvantages
   - Vision camera and sensor quantum efficiency and spectral range
   - Illumination techniques and their application fields relative to surface flatness and surface reflectivity
2. Familiarity with the 4 cornerstones of vision illumination:
   - Geometry
   - Pattern, or structure
   - Wavelength
   - Filters
3. Detailed analysis of:
   - Immediate inspection environment – physical constraints and requirements
   - Sample – light Interactions with respect to your unique samples

When the information from these three areas is accumulated and analyzed, with respect to the specific sample and inspection requirements, we can achieve the primary goal of machine vision lighting analysis - to provide sample appropriate lighting that meets three acceptance criteria consistently:

1. Maximize the contrast on those features of interest
2. Minimize the contrast elsewhere
3. Provide for a measure of robustness

As we are all aware, each inspection is different, thus it is possible, for example, for lighting solutions that meet Acceptance Criteria 1 and 2 only to be effective, provided there is no inconsistencies in part size, shape, orientation, placement, or environmental variables, such as ambient light contribution (See Figure 1).

Figure 1 - Cellophane wrapper on a pack of note cards. Left: Meets all 3 acceptance criteria. Right: Meets only criteria 1 & 2. In this circumstance, the "wrinkle" is not precluding a good barcode reading, but what if the "wrinkles" were in a different place in the next pack on the line?

2. Vision Illumination Sources and Spectral Content

The following lighting sources are now commonly used in machine vision:

- Fluorescent
- Quartz Halogen – Fiber Optics
- LED - Light Emitting Diode
- Metal Halide (Mercury)
- Xenon
- High Pressure Sodium

Fluorescent, quartz-halogen, and LED are by far the most widely used lighting types in machine vision, particularly for small to medium scale inspection stations, whereas metal halide, xenon, and high pressure sodium are more typically used in large scale applications, or in areas requiring a very bright source. Metal halide, also known as mercury, is often used in microscopy because it has many discrete wavelength peaks, which complements the use of filters for fluorescence studies. A xenon source is useful for applications requiring a very bright, strobed light. Figure 2 shows the advantages and disadvantages of fluorescent, quartz halogen, and LED lighting types, and relevant selection criteria, as applied to machine vision. For example, whereas LED lighting has a longer life expectancy, quartz halogen lighting may be the choice for a particular inspection because it offers greater intensity.

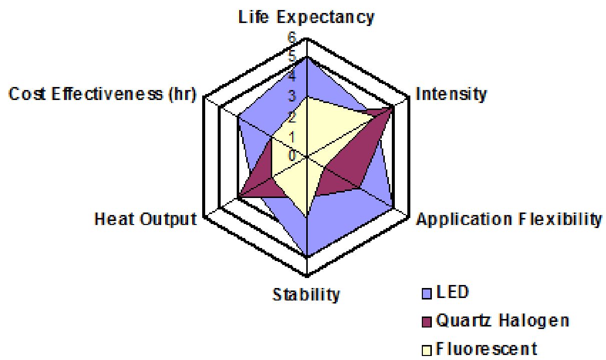


Figure 2 – Comparison and contrast of common vision lighting sources.

Historically, fluorescent and quartz halogen lighting sources have been used most commonly. In recent years, LED technology has improved in stability, intensity, and cost-effectiveness; however, it is still not as cost-effective for large area lighting deployment, particularly compared with fluorescent sources. However, on the other hand, if application flexibility, output stability, and longevity are important parameters, then LED lighting might be more appropriate. Depending on the exact lighting requirements, oftentimes more than one source type may be used for a specific implementation, and most vision experts agree that one source type cannot adequately solve all lighting issues.

It is important to consider not only a source's brightness, but also its spectral content (Figure 3). Microscopy applications, for example often use a full spectrum quartz halogen, xenon, or mercury source, particularly when imaging in color; however a monochrome LED source is also useful for a B&W CCD camera, and also now for color applications, with the advent of "all color – RGB" and white LED light heads.

In those applications requiring high light intensity, such as high-speed inspections, it may be useful to match the source's spectral output with the spectral sensitivity of your particular vision camera (Figure 4). For example, CMOS sensor based cameras are more IR sensitive than their CCD counterparts, imparting a significant sensitivity advantage in light-starved inspection settings when using IR LED or IR-rich Tungsten sources.

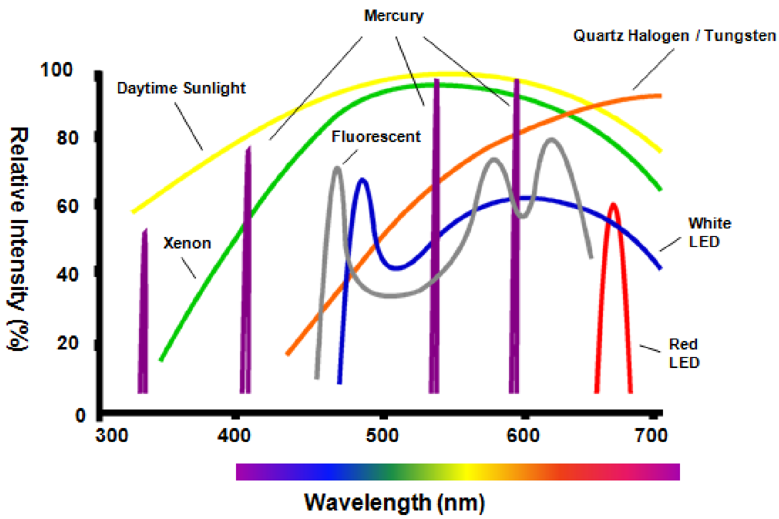


Figure 3 – Light Source Relative Intensity vs. Spectral Content. The bar at the bottom denotes the approximate human visible wavelength range.

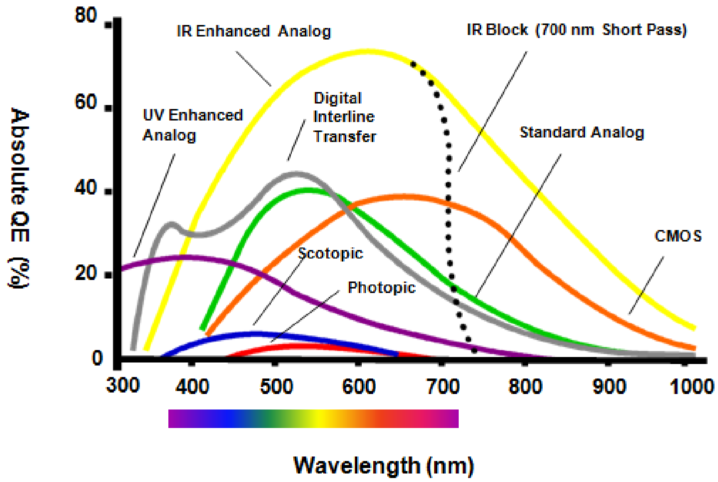


Figure 4 – Camera Sensor Absolute Quantum Efficiency vs. Wavelength. The bar at the bottom denotes approximate human visible wavelength range.

Additionally, the information in Figure 3-4 illustrates several other relevant points to consider when selecting a camera and light source.

- Attempt to match your sensor's peak sensitivity with your lighting source's peak wavelength to take the fullest advantage of its output.
- Narrow wavelength sources, such as monochrome LEDs, or mercury are beneficial for passing strategic wavelengths when matched with narrow pass filters. For example, a red 660 nm band pass filter, when matched to red LED light, is very effective at blocking ambient light on the plant floor from overhead fluorescent or mercury sources.
- Sunlight has the raw intensity and broadband spectral content to call into question any vision inspection results – use an opaque housing.
- Even though our minds are very good at interpreting what our eyes see, the human visual system is woefully inadequate in terms of ultimate sensitivity and spectral dynamic range – let your eyes view the image as acquired with the vision camera.

3. The Cornerstones of Vision Illumination

The 4 cornerstones of vision illumination are:

1. Geometry - The 3-D spatial relationship among sample, light and camera.
2. Structure, or Pattern - The shape of the light projected onto the sample.
3. Wavelength, or Color - How the light is differentially reflected or absorbed by the sample and its immediate background.
4. Filters - Differentially blocking and passing wavelengths and/or light directions.

Understanding how manipulating and enhancing sample contrast using the 4 cornerstones is crucial in meeting the 3 aforementioned acceptance criteria for assessing the quality and robustness of lighting. Effecting contrast changes via geometry involves moving the sample, light, and/or camera positions until a suitable configuration is found. For example, a co-axial ring light (one mounted around the camera) may generate hot spot glare on a semi-reflective bar code surface, but by simply moving the light off-axis, the hot spot glare is also moved out of the camera's view. Contrast changes via structure or the shape of the light projected on the sample is generally light head or lighting technique specific (see later section on Lighting Techniques in Part II of this series). Contrast changes via color lighting are related to differential color absorbance vs. reflectance (See Sample – Light Interaction in Part II).

4. Related Links

Continue to Part II and Part III of this three part series to learn more about machine vision lighting concepts and theories. Part II introduces factors to consider when designing a machine vision lighting system. Part III introduces various lighting techniques and a method for systematically designing a robust lighting system.

- Practical Guide to Machine Vision Lighting – Part II
- Practical Guide to Machine Vision Lighting – Part III