Illumination

Optimizing Illumination for Linescan Vision Systems

An overview of illumination techniques used in linescan and web inspection applications

White Paper

StockerYale

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Introduction

Illuminators for machine vision have historically been designed by adapting readily available, mass-produced illumination technologies to suit individual machine vision applications. These standard illumination sources, e.g. fluorescents and incandescents, were originally developed for mass-market deployment in domestic automotive and display technologies. While the main advantage of these lighting sources is low cost, they are often not suited for scientific or instrumentation vision systems.

This white paper looks at the particular case of linescan machine vision applications and argues that users select a no-compromise illumination method in order to meet the demands of today's sophisticated machine vision systems. Furthermore, the paper will demonstrate that StockerYale's COBRA™ LED technology provides the machine vision designer with increased performance, reliability, and longevity, over traditional illumination techniques.

Types of Machine Vision Systems

2D Inspection

In its simplest form, 2D inspection involves detecting for the presence or absence of a product, property, feature, or line. These applications generally have well-defined pass/fail criteria. Applications commonly include character or feature recognition, while more advanced systems can perform physical measurements on parts and do not require complex illumination schemes. A single light source that provides a 'soft' and repeatable flood is usually adequate. The most important consideration for these applications besides "does it work?" should be "is it reliable?"

Today, complex 2D machines with simple illumination needs dominate the machine vision market. As speed requirements increase, more light is generally needed to compensate for faster processing speeds. Many of these application types use 'smart cameras' equipped with standard simple monochrome LED sources. The low cost of these sensors (camera, illuminator, processor) has led to their quick and broad acceptance in the market.

1D or Linescan Inspection

A different approach is required when materials are produced on a web or large sheet basis, especially when high-resolution defects need to be identified quickly and continuously. The modern production of important, low-cost materials such as plastics, metals, glass, and paper call for large investments in capital equipment. In today's world, these machines include vision systems that constantly measure and inspect materials, often 24/7. Furthermore, all aspects of production need to be fully controlled and continuously improved in order to satisfy the high quality demands expected from industry and consumers.

The cameras that are used in linescan applications are most commonly monochrome, with image pixel sizes that range from several millimeters to a few microns in diameter, depending on the application type. In situations where the application requires the use of fine pixilation and/or fast processing speeds, a high-brightness illumination source is essential to achieve optimal inspection results.

Lighting Techniques for Linescan Applications

The successful implementation of a linescan machine vision system will depend as much on its method of illumination, as it does on its camera system. There are three principal classes of linescan applications, each with different illumination requirements. Here, we attempt to identify the most important features of each.

1. Top Diffuse

Top diffuse systems include inspecting printed paper, bare PCBs, fabrics, plywood, non-reflective films, etc. where the camera and the light source are on the same side of the non-shiny substrate. The most important requirements are power/speed, contrast, and stability. Consistency is also needed if multiple vision systems are being built. Less important is perhaps uniformity.

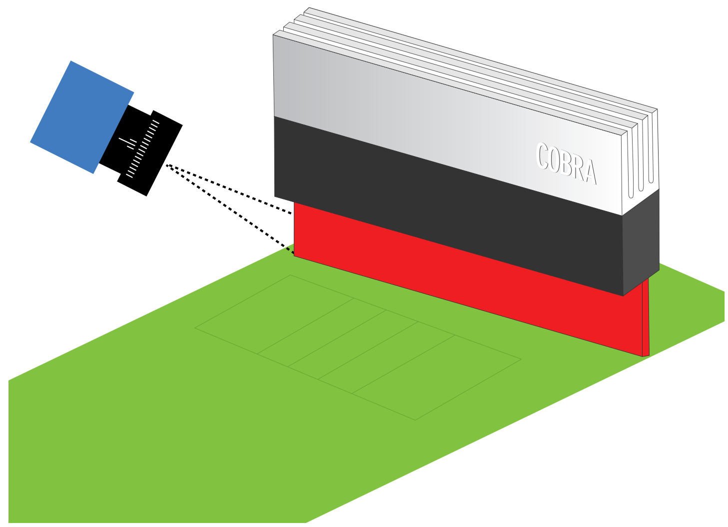


Figure 1: Top diffuse illumination

2. Front and Back Specular

Front and back specular machines often inspect the surface quality of a substrate for very fine defects or features. These systems are very demanding of illumination with respect to precision, uniformity, and stability. This is especially true as the defect size and camera pixel sizes become smaller.

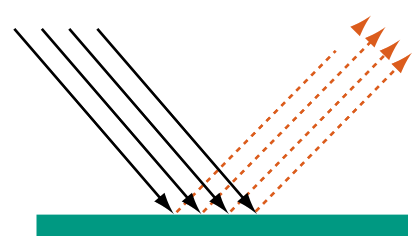


Figure 2: Specular reflection (smooth surface)

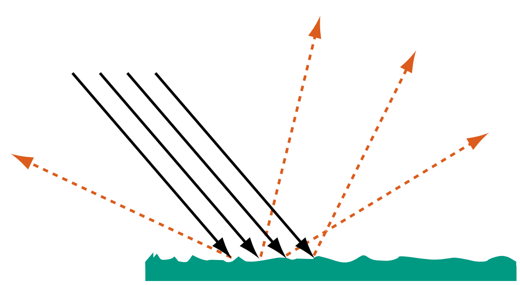


Figure 3: Diffuse reflection (rough surface)

3. Back Diffuse

In back diffuse systems, the camera and illuminator are on opposite sides of the substrate and the camera is directly "looking at" the illuminator. Here, simple perforations in the substrate is the only issue. Power is less important because the camera will detect increased levels of illumination where there is a hole. If more qualitative measurements (e.g. opacity) are needed, then uniformity becomes very important. Again, consistency and reliability of the illumination source are critical not only to inspection, but also to the overall manufacturing system's performance and uptime.

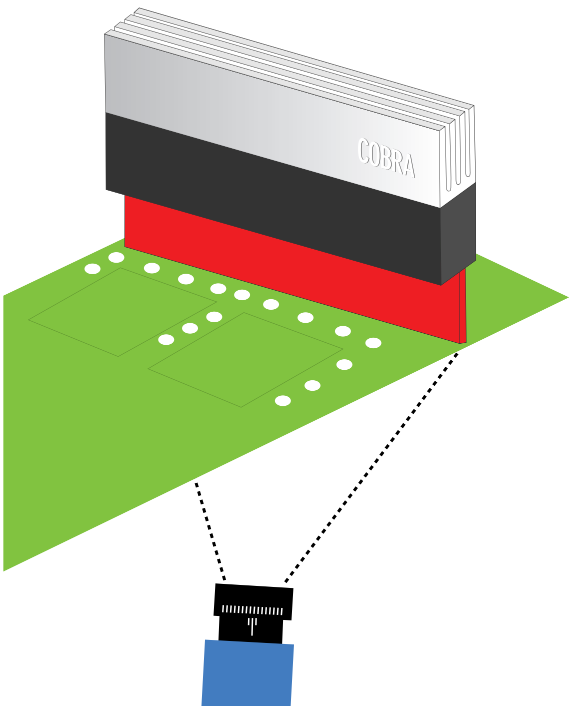


Figure 4: Bottom diffuse illumination

Traditional Linescan Illumination Technologies

The ability to identify a defect depends directly on the capacity to generate image contrast, which in turn relies on illumination level, spectrum, and geometry. Although there are many illumination technologies and products that target linescan application users, none of them meet all the requirements of today's complex machine vision systems. The following section evaluates each of these technologies and outlines the key advantages and disadvantages.

Fluorescents

Fluorescent illuminators consist of tubes of mercury vapor that are excited by alternating current. UV emissions cause phosphors on the walls of the tube to fluoresce with white light. Despite their relative low intensity, fluorescents have remained a popular choice for top diffuse inspection applications due to their low cost and well-defined lifetime specifications. However, fluorescent lights suffer from several disadvantages once system demands rise:

- The chrominance and luminance of the tubes are temperature-dependent. Warm-up times must be considered and in some cases, the temperature needs to be stabilized.
- Fluorescent tubes are difficult to fire at temperatures near zero degrees.
- Light is not uniform along the length of the tube. Over the lifetime of a tube, the ends (approx 3") fade more quickly than the center.
- A single fluorescent tube is limited to a length of 8 ft.
- Application designers must ensure that the ballast frequencies of the fluorescent tubes do not beat with the linescan camera causing a modulation of the camera images.
- The emitted spectrum from the fluorescent tubes are difficult to control. Spectral changes in tubes may result in changes in color and therefore image changes.
- Wide spectral emission from the tubes may reduce the overall resolution of the system by highlighting chromatic aberration artifacts from the imaging lens.

Fiber-Delivered Halogen (FDH)

This is the most commonly used illumination solution in high-speed linescan applications where increased intensity is required.

In general, fiber-delivered halogen illuminators consist of a powerful halogen bulb (50-200 W) that emits broadband black body radiation. The bulb is mounted on a reflector and directed at a bundle of optical fibers. The fiber bundle is then distributed into a narrow line. Cylindrical optics may be used to further focus the light depending on the application. Very high intensities can be generated at the ends of the fiber bundle. The key advantages of this scheme are that the 'business end' of the illuminator is made of very robust glass fiber, and that the heat of the bulb is kept well away from the inspected substrate. On the other hand, there are some key weaknesses:

- The bulbs typically have a short life (< 3,000 hours), if driven hard.
- The bulbs fade and change color before they ultimately fail.
- New replacement bulbs illuminate the fiber bundle (and therefore the line) differently, hence affecting repeatability.
- Great care must be taken to mix the fibers randomly when manufacturing the illuminator in order to maximize the uniformity of the light along the line under all conditions.

Fiber-Delivered Metal Halide (FDMH)

Fiber-delivered metal halide sources are similar in construction to FDH sources, although they have a number of distinct advantages over FDH. Namely, FDMH systems have higher electrical efficiency (less heat emission), longer lifetimes (up to five times longer), and also have a white spectrum constructed from discrete narrow emissions bands. These benefits would seem to make them a more obvious choice for machine vision, however intensity is very difficult to control and the replacement of metal halide sources is far more expensive than halogen bulbs.

LED (Standard Packages)

LEDs are semiconductor devices that are packaged usually in a way that is optimized for use in display technologies. At the center of these devices is a very small (250 µm x 250 µm) die of light emitting semiconductor material. These individual packaged parts are easily mounted and connected to each other using standard printed circuit board manufacturing techniques. Furthermore, they are generally very reliable, provided that they are not too densely arranged where overheating can become a problem.

With regards to efficiency, LED packages in the visible spectrum can be compared to that of a halogen bulb. Standard LED packages are usually compact but not very powerful. Arrays of tens or hundreds of LED chips are necessary to create a sufficient amount of light for inspection purposes. Although LED packages offer reliable and controllable illumination that can be easily designed and is highly adaptable, they have some limitations when used in linescan applications:

- The achievable intensity from devices constructed using standard LEDs is severely limited by its optical and thermal design.
- The radiance of standard LED packages is quite low and no amount of optics can improve this.

The Optimal Solution: COBRA™

Chip On Board Reflective Array (COBRA) LED Arrays

This patented technology from StockerYale is the result of a unique approach to the linescan illumination challenge. Through careful design, COBRA™ achieves a powerful, stable, and reliable LED line light source that is ideal for high-end applications where performance is critical and down time is unacceptable. Here, the line of light is assembled by imaging light directly from a very bright row of LED semiconductor devices onto the inspected substrate. Placing the LED semiconductor dies almost touching one another and directly in contact with a powerful cooling system allows the COBRA™ Linescan Illuminator to deliver unprecedented levels of intensity from an LED product. The efficiency of the product is further enhanced by placing a miniature reflector around each LED light source (Figure 5), which in turn focuses more of the LED light forward to where it is needed.

Longevity

Lab tests of over 10,000 hours have shown a less than 5% change in light output with our standard 630 nm product. All COBRA™ Linescan Illuminators are factory burned-in for at least 24 hours. For shipments manufactured in the last two years, no field failures for LEDs have been recorded.

Each individual substrate (containing approximately 100 LEDs) has its own over-temperature monitoring and protection features. Should the unit overheat for any reason, it will automatically shutdown. The user is provided with an electrical alarm indicating a fault condition.

Uniformity

All COBRA™ Linescan Illuminators are factory-adjusted so that each internal substrate is set to a calibrated optical power level. This way, the overall power of the illuminators is fixed and uniform. The user simply has to plug in the unit and a fixed, constant level of light will be achieved. Should the replacement of a light or segment of light be necessary, there would be no need for system adjustment or re-calibration.

Power

By virtue of its advanced optical design and superior thermal performance, the COBRA™ delivers unprecedented levels of intensity from an LED product. The optical power achievable from StockerYale's patented line light is comparable in intensity to that of a fiber-delivered line light, but with the advantage of better uniformity, stability and longevity.

Control

Should the user want to adjust the brightness, a simple 0-5 V control input enables the user to linearly adjust the current (and therefore the brightness) of all LEDs simultaneously, regardless of unit length.

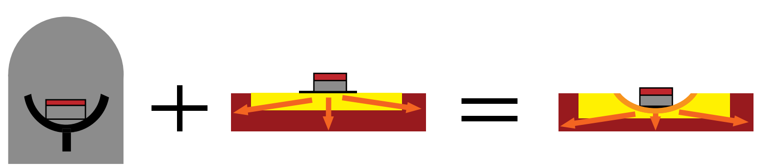


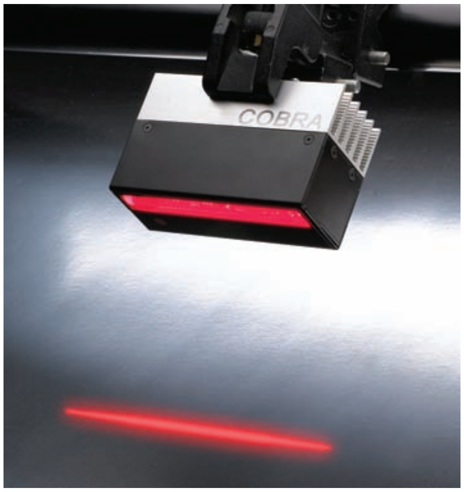
Figure 5: The optical efficiency of a reflective cup is combined with the superior thermals of chip on board (COB) in the proprietary COBRA™ array method.

Repeatability and Stability
All illuminators are factory calibrated and shipped at the same optical power setting. Therefore, a COBRA™ Linescan Illuminator purchased today will offer the same consistent performance as a unit purchased many years from now. In addition, pointing accuracy of < 0.5 degrees is also factory set.

Contrast
The ability to deliver light at one wavelength offers the machine vision system designer more scope to enhance contrast. Machines built using white light and monochrome cameras do not necessarily offer the optimum contrast, i.e. red objects may appear the same as green and are therefore indistinguishable. In older systems, white light filters were typically used to improve the overall contrast of the system, but at the cost of reducing intensity. In the majority of applications, well-chosen monochrome illumination generally offers more contrast. By using high power COBRA™ Linescan Illuminators, which are available from UV through visible to IR wavelengths, designers can optimize contrast without compromising image brightness or sensitivity.

Cost of Ownership
COBRA™ Linescan Illuminators are similar in cost to a good quality fiber optic illuminator, but offer far greater levels of performance, control, and consistency. More importantly, there are no bulbs to change, no light levels to adjust, and no unevenness issues to correct. Furthermore, there is no downtime due to lamp failure or degradation.

Conclusion



COBRA™ Linescan Illuminators are the first machine vision illuminators on the market that have been designed from the 'ground up' to function optimally and reliably in demanding machine vision applications. Its uniquely patented features, ease of use, cost effectiveness, and application-oriented design, offer major advantages for machine vision system designers who wish to incorporate linescan illumination systems in a wide range of industries and applications.

Technology	Image Contrast	Power	Uniformity	Repeatability	Lifetime	Stability	Control	Cost per month	Cost of ownership
COBRA™ (Chip-On-Board Reflective Array)	• • • •	• • • •	• • • •	• • • •	• • • •	• • • •	• • • •	High	Low
Fluorescents	•	• • •	• • •	• •	• • •	•	• •	Low	Low
FDH (Fiber-Delivered Halogen)	• •	• • • •	• • •	• •	• •	•	• • •	High	High
FDMH (Fiber-Delivered Metal Halide)	• •	• •	• • • •	• •	• • •	•	•	High	High
LED (Standard Packages)	• • • •	• •	• •	• •	• • • •	• • •	• • • •	Medium	Low

Table 1: Comparison of the various linescan illumination technologies on the market.
Poor = • Excellent = • • • •

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StockerYale, Inc. is a leading designer and manufacturer of structured light lasers, LED modules, and fluorescent lighting products, as well as specialty optical fibers and phase masks for industry leading OEMs. Through this diverse product mix, the company serves a wide range of markets including the machine vision, industrial inspection, defense, telecommunication, sensors, and medical markets.

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