Application Note | Case Study | Technology Primer | **White Paper**

Evaluating Color Inspection: Can Color Machine Vision Improve Results?

Machine vision has evolved to become a fast and reliable tool for quality inspection. In many cases, a machine vision optical inspection system can perform quality inspections more quickly and accurately than humans and at a lower cost. However, can a machine "see" in color? And, does introducing color into the equation help with quality inspection?

A machine vision system acquires images of an object with a camera, and then uses computers to process, analyze and measure various characteristics of that object so decisions can be made. One of the characteristics analyzed can be an object's color.

In the past, color has not been widely used in optical inspection because of the cost and processing power required. However, as costs decrease and processing power ceases to be an issue, solutions providers are looking at incorporating color into machine vision optical inspection systems to yield greater quality.

This article will discuss how color machine vision works, and why color can be beneficial in machine vision applications.

Color is Better, Right?

The basic assumption is that color is more "advanced" than black and white, or monochrome, so it must be better. However, this assumption is not always true in machine vision. In typical inspection applications where defects like cracks or scratches are detected, the use of color is not necessary, because the goal is to discern a difference in lightness on the object's surface.

There are also some things that monochrome cameras do better than color cameras. Take resolution and speed for example, there are more choices in high resolution and high speed when shopping for monochrome cameras. In addition, there are many cases where color images do not offer any advantage over monochrome images in resolving a machine vision problem, such as Optical Character Recognition (OCR), Optical Character Verification (OCV), bar code reading, gauging and other applications that are dependent on high-resolution spatial information.

How Machines "See" in Color

Of course, a machine can not actually see in color. Machines use mathematical models to approximate human color detection. A machine can be calibrated against the average human response to color and hence "see" in that it gives consistent responses to colors observed in a controlled setting. This "calibrated color vision" is useful for measuring and matching colorants in paint, plastics, fabrics, etc. We don't think of this as "seeing" color like a human, except perhaps as a philosophical exercise. However, it is important to make the distinction between the relative measurements that can be made with a machine vision system versus absolute measurements that are only possible with devices such as photospectometers.

Human color vision evolved to reliably extract information about the "material properties" of objects seen under huge variations of illumination and view. For example, fruit color has to be reliably determined despite varying illumination to pick ripe from unripe or bad fruit. Human color vision thus has mechanisms to "factor out" variations in illumination and view that we don't know how or don't bother to put into machine color vision. Human color vision is relative. Nearby colors influence the perception of a color, it has low resolution (a fact used to transmit color in television with very little bandwidth), and there are wide differences between individuals, and thus is not a good measuring tool. Machine color vision is not influenced by nearby colors, can have high resolution, does not vary much from machine to machine, and thus is a good measuring tool.

Types of Color Machine Vision Systems

Most color machine vision systems use a mix of hardware and software to detect colors. For point or "spot" color measures, a mostly hardware solution is fine. Sophisticated detection systems rely more heavily on software, to give flexibility to designer and user.

The main types of color cameras used in machine vision applications are 3CCD, tri-linear and Bayer pattern cameras. 3CCD has excellent color registration and can be applied to the majority of applications. However, the cost is high due to the design.

Trilinear provides high performance and has advantages in terms of its low-cost. It can be used in many applications such as flat surface inspection. However, spatial correction cannot be done properly in certain applications which involve rotating or randomly moving objects.

Finally, Bayer pattern cameras round out the mix offering the lowest cost solution. These cameras are not recommended if color precision is the most important aspect of your application).

When to Use Color

In typical inspection applications where defects like cracks or scratches are detected, the use of color is not necessary because the goal is to discern a difference in lightness on the object's surface.

Aside from the obvious applications where the color of an object needs to be evaluated in some way, color can sometimes help to make an inspection situation easier by facilitating the identification of objects, such as in the verification of fuses values in car fuse boxes.

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Should color eventually be used in all MV applications? No. Because, there are some things that monochrome cameras will always do better than color cameras. Take resolution and speed for example, you will find more choice in high resolution and high speed if you are shopping for a monochrome camera. In addition, there are many cases where color images do not offer any advantage over monochrome images in resolving a machine vision problem.

When faced with an application that instills some doubt, ask yourself the following questions:

- Is the object's color quality and consistency a key factor in the overall quality of your product?

- Can the object's color help you to ascertain the relative quality of your product?

- Will color facilitate detection of the object?

If the answer to any of these questions is yes, then you should take a serious look at the color side of machine vision.

Applications

Let's look at a few real world applications that will help facilitate the decision of whether or not color should be part of your application.

Food is probably the one application area that everyone inherently understands the best because as daily consumers of food, we are constantly judging the quality and consistency of the food we buy. For fruit, color allows us to ascertain ripeness and grade product quality (nobody wants to buy a blotchy orange or a half yellow lime). In the case of grains and legumes, color helps to grade product quality and distinguish foreign matter in a steady stream of product.

In meat processing, color can be used to detect spoilage and discriminate areas of fat, bone and gristle for automatic trimming. Why color machine vision is even used to inspect the 'build' quality of frozen pizza! Think about it, with a monochrome image, you might be able to tell if the density of ingredients is correct (i.e. enough of them and if they are properly spread out). But you will have a great deal of trouble telling the difference between some of the chopped ingredients. Take for example, orange, red and green peppers. In color, they are easy to tell apart, in monochrome, not so much.

Another area where color machine vision is used is in automotive inspection. Although you may think that a car's paint would be where machine vision is used, the bulk of the effort goes into inspecting the fine visual details that make up the user interface. For example, making sure the consistency and evenness of the instrument-cluster light panel. This is important because the look and overall quality of the instrument-cluster and dashboard go a long way towards contributing to driver's impression of a car's quality.

Obviously, there many other applications that could require color, such as print inspection (quality/registration), pharmaceutical inspection (label verification), part presence and/or detection, PCB assembly (part presence, verification and placement). In addition, there's a slew of quality and grading applications that involve color and texture classification for things like wood, textiles and ceramic tile to name just a few.

What different types of color machine vision cameras exist and how are they different?

The main types of color cameras used in machine applications are 3CCD, tri-linear and Bayer pattern cameras. These can be either area scan or line scan cameras depending upon the type of color incorporated.

Camera Types	Area Scan	Line Scan
3CCD prism camera	Common	Common
Tri-linear	Not applicable	Common
Bayer pattern camera	Common	Not applicable

3CCD has excellent color registration and can be applied to the majority of applications. However, the cost is higher due to the design. In a 3CCD color camera, color is selected using a prism-based interference filter that splits the incoming light into Red(R), Green (G) and Blue (B) primary components. Each of the three primary colors is then detected by a CCD respectively and the final color image is reconstructed by combining the outputs from the three CCDs. All three color images are captured at the same object spot and at the same time.

Tri-linear provides high performance and has advantages in terms of its low-cost. It can be used in many applications such as 100% print inspection. However, spatial correction cannot be done properly in certain applications which involve rotating or randomly moving objects. In a tri-linear color camera, three linear arrays are fabricated on one single die and coated with RGB color filters respectively. These are absorbing filters using dye or pigment. In the tri-linear camera, the three linear arrays detect a slightly different field of view (FOV) of the object and spatial correction is needed in the re-construction of a color image.

Finally, Bayer pattern cameras round out the mix offering the lowest cost solution. These cameras tend to be used in lower-end applications as and have reduced color precision as compared to 3CCD and tri-linear cameras. However, there is broad understanding of the Bayer pattern and many algorithms exist to optimize its color performance.

DALSA offers the Genie, Trillium and Piranha color cameras for machine vision each based on a variety of distinct color imaging technologies, including: Bayer color filter array, beam splitter prism and tri-linear sensor.

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How does color detection work in terms of hardware (cameras)?

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What role does software play in color detection?

Most color machine vision systems use a mix of hardware (the camera, color space conversion, etc.) and software to detect colors. For point or “spot” color measures, a mostly hardware solution is fine. Sophisticated detection systems are mostly software, to give flexibility to designer and user. Major differences in approaches are in the color “classifier” that detects colors – assigns color pixels to a class such as “good” or “defect”. A good classifier has some tolerance to illumination changes (robustness), is quick to train and run, and reliably assigns pixels to their correct classes. Classifiers are an area of continuing development and competition between vendors.

The Future of Color Machine Vision

Market studies by the Automated Imaging Association (AIA) show that only about one-fourth of cameras sold for imaging applications in 2005 and 2006 were color cameras with the remaining three-fourths as monochrome, but the trend for color is upward.

Most experts in the field believe the use of color will expand in machine vision. Color provides much more visual detail than monochrome grayscale and adds a new dimension in analyzing data in the real world. For example, color is increasingly being adopted in bank note inspection applications for scanning and processing. In some Asian countries, color inspection is required by the government as people use personal seals rather than signatures in issuing personal checks. The seals are usually used with red ink that has poor contrast in monochrome system. It is normal for banks to require a color report to confirm authenticity. Another example is printed circuit board (PCB) inspection applications in which color cameras are used to identify oxidized copper wires that are otherwise difficult to see in a monochrome system.

In terms of new technology, DALSA has developed both 3CCD and tri-linear technologies and has been supplying high performance color cameras to the industry with much success. Better color fidelity, lower cost and ease-of-use are the primary drivers in the market and new technologies being developed in the near future to address these needs and to meet the increasing demand of these products.

About the Author

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