

# Optical Filter Kit Colors Machine Vision



*Testing and controlling the variables with filters*

**By Jason Dougherty**

**M**achine vision integration is in some ways similar to conducting a science experiment. In order to produce meaningful results, it is first important to identify and control the variables that can influence the outcome. Light is always a consideration when developing any vision system, and more often than not it is the most difficult and most important variable to control. Of all available tools, we will show why the simplest, quickest and most cost effective way to improve repeatability and stability in any system is through the use of optical filtering. Optical filtering therefore should be given primary consideration and not treated as a secondary accessory or as an afterthought. In order for "integrator scientists" to reach a better understanding of how and why this is so, MidOpt has created a "Machine Vision Filter Kit" to aid in the design of industrial imaging systems.

The **MidOpt FK100 Machine Vision Filter Kit** was created as a tool to allow vision integrators to quickly test some of the most commonly utilized optical filtering options and develop an understanding of how and why certain filters can be useful in specific situations.

In this kit, filters and associated information are placed in clear protective sleeves with pockets and stored in a binder for use as a resource in the vision lab or for easy transport to the factory floor. Each sleeve contains the corresponding filter transmission

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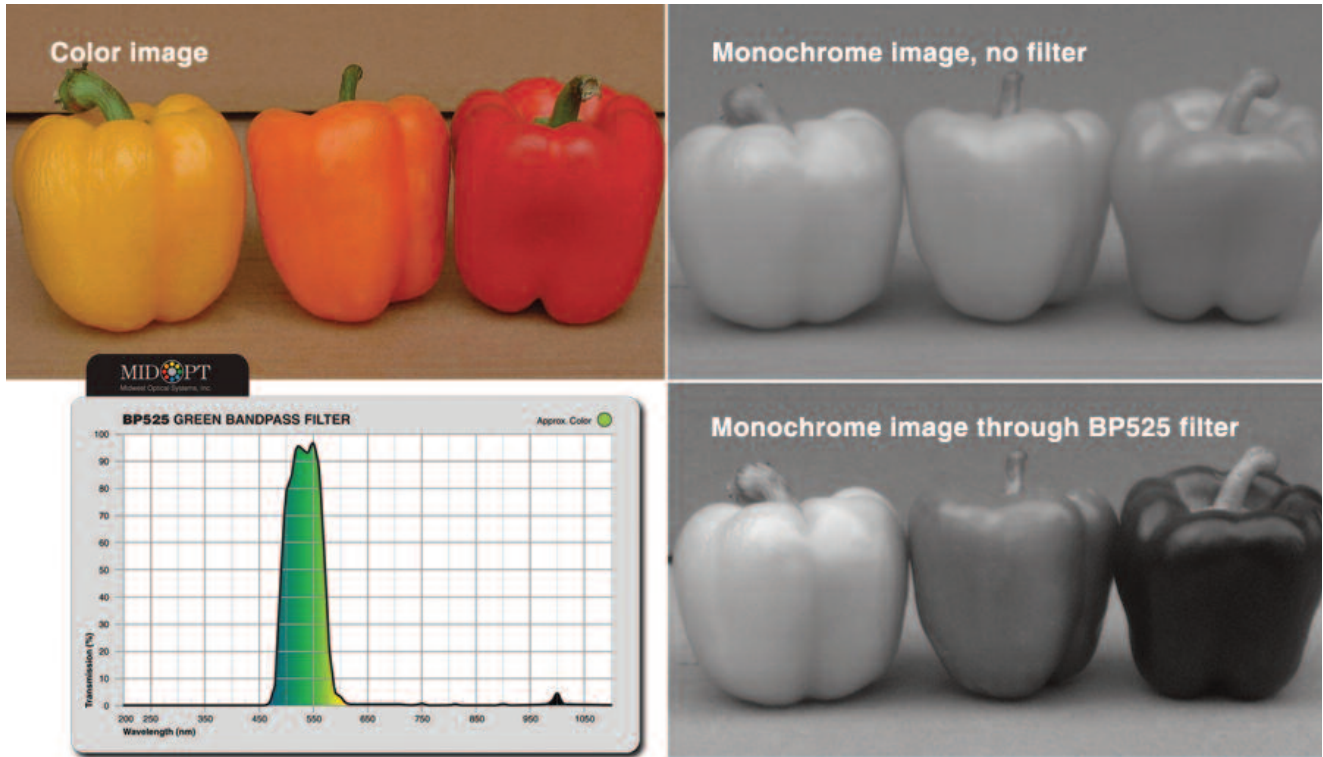
**FIGURE 1**

curve, table of spectral data points, example photos and illustrations to show how each filter can be put to use. The kit also provides useful information to foster an understanding of how filters can be matched to the subject, camera, lighting, and lens to improve system reliability and image quality. To describe some of these benefits, an explanation of how machine vision filters can best be utilized follows.

## **CAMERAS AND FILTERS**

Currently the use of color cameras in vision inspection is an increasingly hot topic. At the same time, cameras in general have been steadily improving as far as resolution and processing capabilities. These improvements have made color inspection more feasible in certain applications where monochrome cameras apparently cannot do an

adequate job. In particular, color sorting applications come to mind. A highly saturated color may appear much more pronounced to the eye, but to the camera it becomes hard to distinguish this from a similar, but less saturated color; e.g., when trying to differentiate between components that are light blue and medium blue in color. Everyone can agree that there are indeed many applications that are better served by using color cameras. Recent interest and improvements related to color imaging have no doubt increased the capability of industrial vision systems to solve a greater variety of quality-related issues, but perhaps have also helped to create a false impression that color is the wave of the future for all industrial inspection applications. This is partly due to how we, as humans, are used to looking at an image – in color. But it should be kept



**FIGURE 2**

in mind that in most cases we are not analyzing the image ourselves. It's being analyzed through an imaging system, software and computer processing. Optimizing these systems to produce as much useful and usable data as possible is the ultimate goal. Color cameras inherently have many shortcomings in that context.

Inconsistent illumination in any application can affect the perceived color values and throw off a system's reliability. To help with this, software suppliers give integrators the ability to control color these differences using hue, saturation and intensity. Disregarding the intensity allows color rendition to be perceived through hue and saturation with less concern for changing illumination levels. However when using this method, algorithms are used and time and processing power are lost - without a guarantee that intensity changes will not affect performance. An often-used rule of thumb for most color camera sensors is that sensitivity (or quantum efficiency) is  $\frac{3}{4}$  that of their monochrome counterparts. This is because most color cameras use a Bayer filter array over what otherwise is a standard monochrome sensor. In most cases,

there typically are two times the number of green filter pixels (roughly 50% of the total number) as opposed to red or blue pixels (each roughly 25% of the total). When processing the information provided by the sensor, the camera analyzes each pixel's color information, and combined with that of adjacent pixels, recreates (or essentially guesses) at the full-color image. This process itself introduces yet another variable. Errors can occur and resolution loss is inherent. This is most pronounced when detection of a single or a few different colors is all that is required. A prime example where this would usually be true is in fluorescence imaging.

Fluorescence is a phenomenon where the molecular absorption of light energy (a photon) results in the emission of a photon at a longer wavelength. From the standpoint of camera sensitivity, the emission is far less bright when compared to the light source that is used for excitation. In machine vision, UV lighting (often 365nm to 395nm-type LED's) is commonly used to fluoresce a subject under inspection, for example to detect the presence or absence of a sealant. The fluorescence emitted from the material can vary, but is most

commonly a light blue color. Since this is often thought of as a "color" application, often times color cameras are utilized to detect it, however there are numerous reasons why using a color camera is far from ideal in these sorts of applications. As mentioned above, when comparing a color to a monochrome camera with the same sensor type and format, a color camera inherently has  $\frac{3}{4}$  the sensitivity of a monochrome camera. When there is essentially only one color to be detected (usually blue), the cameras sensitivity drops to 25% efficiency when compared with a monochrome version of the same type. This is basically because both the green (50%) and red (25%) pixels are disregarded. This significantly reduces the system's ability to detect an already weak fluorescence. By comparison, a monochrome camera that utilizes the entire sensor to detect intensity, combined with a broad, blue bandpass filter that transmits 90% (or better) of the light entering the camera lens, is only reduced to 90% efficiency. By using a monochrome camera and bandpass filter matched to the fluorescence, the quantum efficiency will be approximately 3.6 times greater, 90% vs. 25% in the case of a color



camera. Of course, this greater sensitivity can be translated into increased speed and accuracy for the system.

The most common application where color cameras are employed is, of course, color sorting. When the requirement is to separate similar colors that vary slightly in their appearance, color cameras have proven to be almost essential. However the variability and issues already discussed are still present. In many of these situations, a more efficient monochrome camera with relatively lower cost could be used. The problem with monochrome sensors is that different colors can be perceived by the camera to have similar intensity, especially when a significant amount of ambient light is also present. However, similar to a photographer using a red filter to darken green foliage in a black and white photograph, color bandpass filters can be used to increase contrast and allow for highly efficient "color" separation. By blocking a particular reflected color from reaching the camera sensor, it will appear darker, while passing these colors will highlight or lighten them. As can be seen in the example, optimal contrast - measured as 0, 127 and 255 grayscale levels (or 100%, 50% and 0% intensity) when dealing with three similar items/colors - can be achieved. (See Figure 2)

In both of the above examples comparing color vs. monochrome cameras, it is easy to understand why a color camera might be the first consideration. Color is what our eyes see and visualizing things in black and white in our minds is not an intuitive process. This especially comes into play when trying to determine which wavelengths (colors) might be isolated in order to benefit system performance. This is one important way in which the MidOpt FK100 Machine Vision Filter Kit can aid in system integration/testing. The kit provides bandpass filters that allow the user to selectively test if a suspected color or wavelength will provide the necessary contrast needed to utilize a monochrome camera. Following testing, if it turns out that full color is what works best, the kit also contains filters that can be used to improve color image quality. These include a light balancing filter (LA120) to knock down the sharp blue spike commonly

associated with white LEDs. Color temperature is adjusted, resulting in a warmer, more accurate color rendition. A visible spectrum bandpass filter (BP550) is also included, which eliminates interference caused by excessive infrared and ultraviolet light. Most importantly, a rotating polarizing filter with locking screw (PR032 for the lens), and linear polarizing sheet (PS007 for the light source) are provided to minimize glare from specular surfaces without affecting color. Since by function a polarizer limits transmitted light, it also acts as a neutral density filter in reducing overall light intensity. Polarizers are, of course, also similarly useful in monochrome imaging applications.

### LIGHTING AND FILTERS

Throughout the brief history of machine vision, lighting has perhaps been the most significant variable causing system failure or lack of success. Most of these problems start with the quality of lighting used within the system, but can at times also be attributed to the ambient light surrounding it. The goal has always been to increase intensity and stability in order to provide efficient capture of images with greater speed and accuracy. The greatest contributions have perhaps come from the widespread usage of and advancements in LED lighting. In recent years this has most significantly been seen in the development of new, higher output LEDs.

Given the recognized significance of lighting in machine vision, it is somewhat surprising that filters are

so often overlooked and underutilized. MidOpt filters are specifically designed to block or pass these select LED wavelengths. However in the past and even today, many filters purchased for industrial imaging applications are unsuitable for their intended purpose. All too often filters that were originally designed for the spectral response of photographic film (400-700nm) are being tested for use in improving an image produced by a digital CCD/CMOS sensor (typically 350-1100nm) together with LED lighting that is often operating over a far more discrete wavelength range relative to the filter being tested in the system. Often the results obtained given these sets of circumstances are less than optimal, if not completely unsatisfactory. As a consequence, filters have often been disregarded as a potential solution or improvement to an inspection application. "They simply didn't do very much," is one comment that is often heard. However a comparison could be made that using a "photographic" filter in a vision system would be like using an incandescent light bulb to illuminate the application. It is far from ideal!

So what constitutes a Machine Vision Filter? It is an appropriately mounted filter designed to selectively pass only the resulting output from light sources integrated into industrial vision applications without significantly limiting intensity or field of view. For example, although the industry has been changing, the LED lighting of choice is still red, and 660nm is still the dominant wavelength. MidOpt has designed the

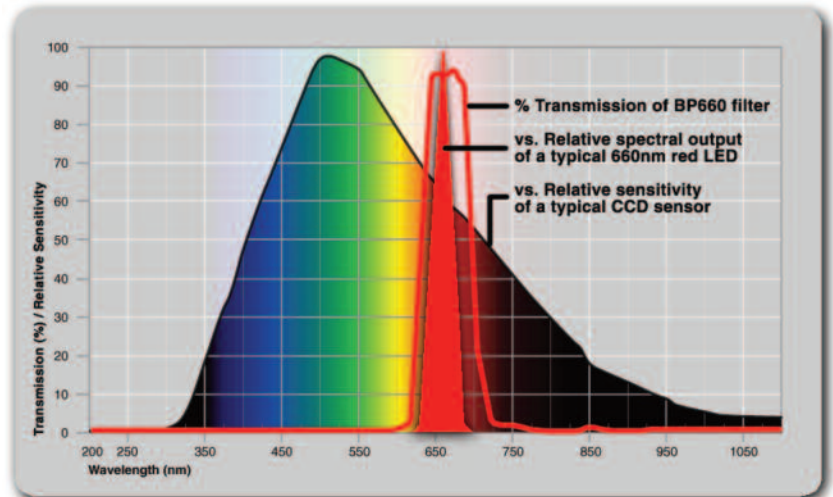
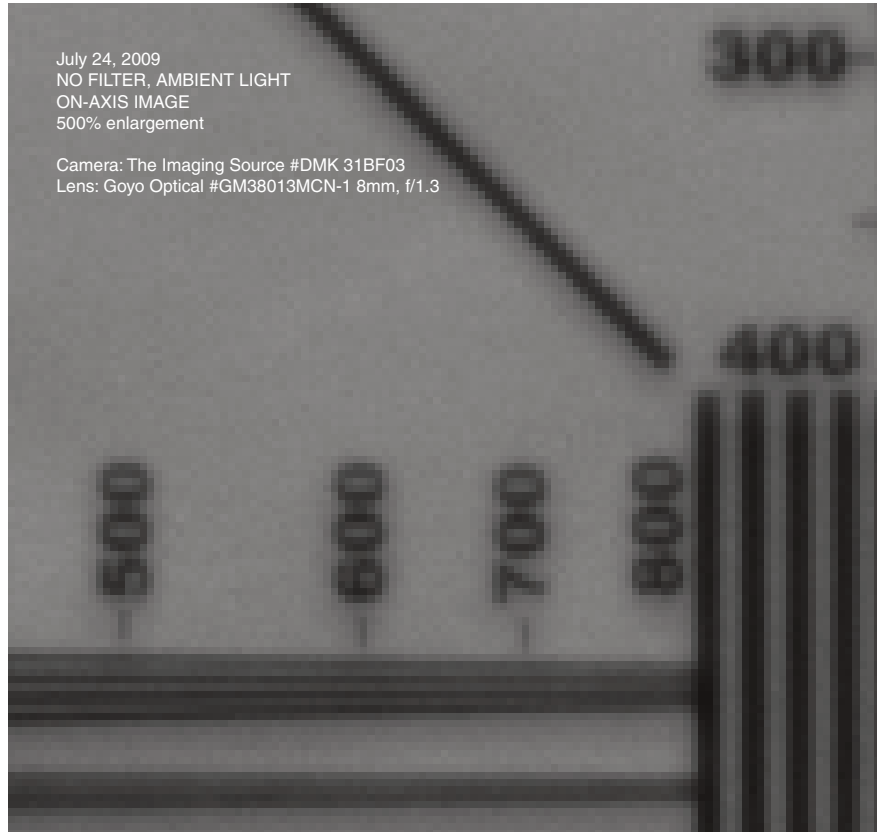


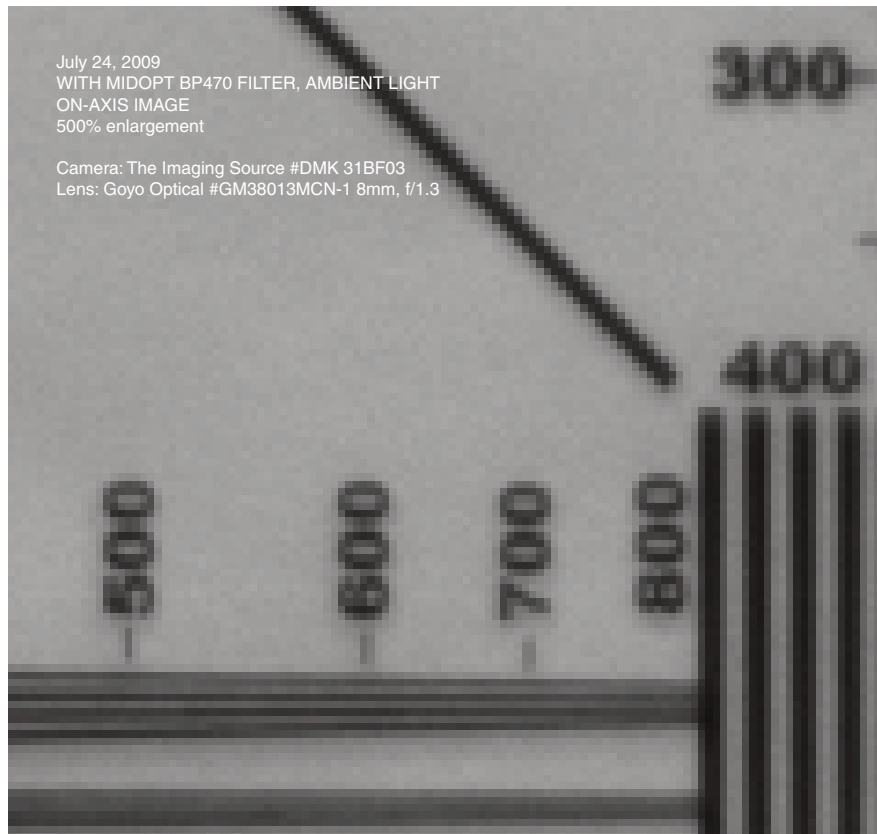
FIGURE 3



BP660 Dark Red Bandpass Filter for use with this type of lighting in mind. As can be seen in Figure 3, the BP660 passes the output from these red LEDs while blocking all other wavelengths from interfering with the CCD/CMOS sensor. This compares to the typical red “photographic filter” or longpass type filter that only blocks shorter wavelengths of light (UV, blue and green) while passing all red and longer wavelength near-infrared light. The additional red and near-infrared blocking achieved when using the BP660 filter results in much better control over the variability of changing ambient light conditions that can greatly reduce contrast or result in system failure. In addition to the longer wavelength blocking, MidOpt Machine Vision Filters are designed to maximize transmission and pass as much of the LED’s output as possible. With this in mind, it is important to recognize why a broad bandpass filter (60-80nm bandwidth) compared to a narrow bandpass (10-40nm bandwidth) is more suitable for machine vision. In attempting to block as much ambient light as possible, narrow bandpass filters are sometimes considered necessary. The problem in using a narrow bandpass filter lies within the LED itself. LED’s have a peak wavelength that is often +/- 10nm away from the specified nominal, with the tail ends of the bell-shaped spectral output curve extending 20-30nm on either side of the peak. As stable and attractive as this type of lighting is, LEDs are still relatively inexpensive, mass-produced items. It is quite common for a light to consist of LED’s shifted in either direction. By using a narrow bandpass filter, it is not unlikely that the light may be shifted to one side of the filter’s transmission band, effectively blocking some, if not most of the light’s output. This becomes especially true when lighting is placed at such an angle relative to the object under inspection that blue shifting can occur due to the angle at which light passes through the filter’s multiple coating layers. This phenomenon can also manifest itself as a darkening of the edges of the field of view when using shorter focal length lenses. Lastly, unlike photographic or narrow bandpass filters, MidOpt filters are offered with mounts that will thread



**FIGURE 4**





into any size lens, or in slip-on mounts that will fit over the outside diameter of lenses without threads (commonly the case with wide-angle lenses) – once again, without cutting off the edges of the field of view. This is in sharp contrast to traditional bandpass filters that are normally offered by other companies in only one or two sizes. As a comparison, most people would not wear eyeglasses that are held together with electrical tape. Not only does this look silly, it is not very permanent or secure. Without an appropriate mount, attaching a filter with glue or duct tape should be viewed in the same way.

Employing a bandpass filter can result in various other less direct benefits. In situations where ambient lighting can be a significant variable, using a bandpass filter will also usually prevent the need to shroud the system. The savings relating to this are many. Initial system costs are greatly reduced, lead time required to bring a system on line can also be greatly shortened, and maintaining a system without having to work in, under or around a shroud becomes a much easier chore. Another important benefit in using a bandpass filter stems from not having to drive a system's lighting hardware to a point where it alone can overcome the detrimental effects of ambient lighting. Not only does this result in energy savings (less power is required to drive LED or other lighting), the lifetime of the lighting hardware is greatly extended.

Understanding what constitutes a machine vision filter, it is appropriate to discuss another advantage of the FK100 Machine Vision Filter Kit. Looking again at the example seen in Figure 3, the BP660 is designed to pass only the output of a 660nm LED, essentially mimicking the LED when used with white light. Within the kit, bandpass filters are provided that are designed for use with most common LED wavelengths, including 365-395nm (UV) 460-485nm (blue), 520-535nm (green), 580-595nm (amber), 620-640nm (light red), 650-670nm (dark red), and 850-880nm (Infrared). One now has the ability to test each wavelength (color) in a system simply by using available white light and changing the filter. Ample ambient light or (ideally) white LED lighting are all that are required.

As the intensity of white LED lighting increases, this is now becoming very practical, eliminating the need to test or be equipped with all of the different LED lighting colors that are available when examining the effects of color in an inspection application. Unless you are an employee of a lighting company, equipping oneself with a large variety of LED lighting options can be rather expensive and unwieldy. However, in the lab or when traveling with a FK100 Filter Kit to the factory floor, any filter can simply be placed over the lens and tested to see if that color/wavelength range provides the required contrast. Testing with MidOpt filters can offer significant savings in terms of time and resources when trying to arrive at an optimal lighting solution. Once an appropriate wavelength range has been determined, a bandpass filter can be used to compliment the chosen lighting and control potential interference from ambient light.

#### LENSES AND FILTERS

Another topic that is currently receiving considerable attention in the machine vision industry is lens and system resolution. As camera manufactures race to offer sensors made up of smaller pixels in greater number, lens manufacturers are struggling to find ways to keep up so that system performance will not always be lens-limited. Often, choosing the best lens for an application can become a trade-off between cost and image quality. Lenses used for industrial imaging are comprised of several lens elements. Each of these elements is designed to focus light onto the camera sensor so that they form an image as accurately as possible. The aim is to reduce aberrations, while using the fewest and least costly design configuration possible. Aberrations can include poor resolution (image blurring), reduced contrast, or defocus of certain colors (chromatic aberration).

All of the above problems exist in some way within any lens regardless of the quality or price. This of course has its disadvantages, especially in gauging applications where high resolution is usually desired in order to provide accurate, repeatable measurements. Filters can benefit most applications where these sorts of problems might

limit performance. The focus of a lens is a function of wavelength. Each different wavelength (color) will focus at different points on or near the image plane, causing loss of resolution. By limiting the wavelength range the lens needs to focus, the result will be a sharper, more easily resolved image. The simplest approach to achieving these results is to use monochromatic lighting with an appropriate bandpass (or monochromatic) filter. The most dramatic results can be achieved when working with shorter wavelengths of light (UV or blue wavelengths).

In FIGURE 4, correction for chromatic aberration is demonstrated with before and after images of a resolution target displaying a sharper, higher contrast image just by using a MidOpt BP470 Blue Bandpass Filter. The image is improved both on and off-axis with a greater increase at the edges (off-axis). This difference from center-to-edge is more pronounced with short focal length lenses, where 20-50% improvements in off-axis resolution have been reported. In this way filtering the light entering the lens can also essentially make a standard lens a poor man's "megapixel" lens.

The purpose of this paper is to outline how and why optical filtering should be considered a primary component used in all industrial vision systems in order to control cost and variables. The MidOpt FK100 Machine Vision Filter Kit, when used as a part of the system design process, is an innovative and invaluable tool that, when utilized properly, can significantly improve short- and long-term outcomes in any machine vision application.



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