Lighting for Color-Based Machine Vision Inspection of Automotive Fuse Blocks

A robust color-based machine-vision system demands careful design and selection of illumination and software to detect the proper placement of automobile fuses prior to chassis wiring.

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During the past decade, machine-vision-based systems have performed as cost-effective inspection tools using gray-scale hardware and software algorithms. More recently, the development of color-based machine-vision systems has expanded the power and diversity of these robust inspection tools. Color provides useful information for object classification, sorting, inspection, verification, and anomaly detection, and color-based machine-vision systems have automated these operations in industrial and biotechnical applications. However, the successful implementation of these color systems requires an expanded level of vision and image understanding.

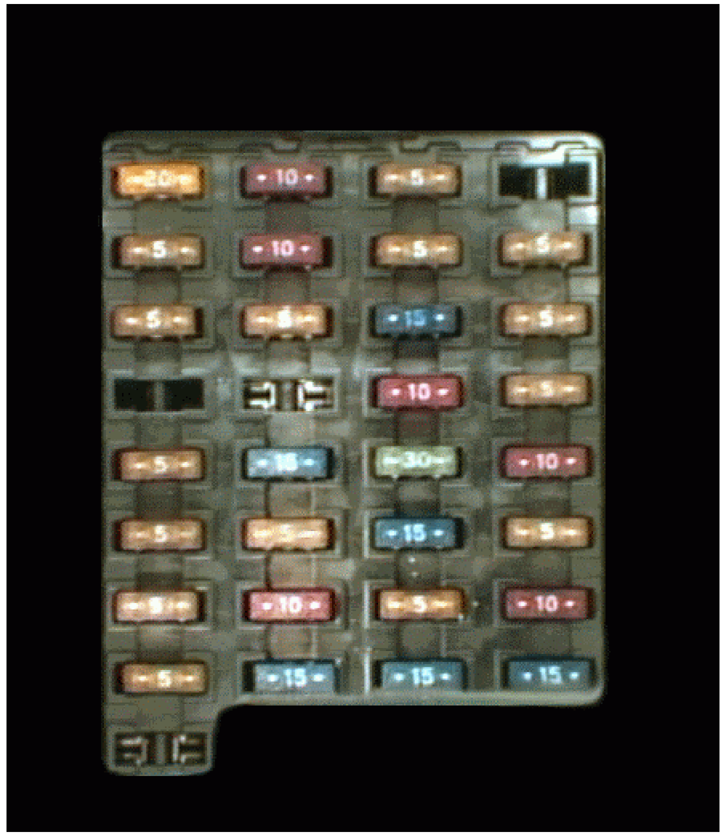

Fig. 1: A typical automotive fuse block. Color coded fuses are pre-inserted into fuse blocks which are then placed into larger dash board or firewall subassemblies. Fuse rating and locations vary depending on make and model and can also come in a variety of size and shapes and color specifications.

A helpful example of a color-vision application involves the placement verification of colored fuses in auto junction boxes. Fuse-block subassemblies are typically populated by a third-tier vendor, then installed into second-tier subassemblies, and, lastly, wired into an automobile chassis.

A misplaced fuse costing a few cents can cause hundreds of dollars worth of rework and overhead when it is discovered in final auto assembly. Even worse, if the defect makes its way into the field, the customer's perception of overall product quality is markedly diminished, and the possible damage, safety, and/or liability issues associated with auto failure due to improper fusing are immense. The high ratio of rework cost to component and inspection costs combined with customer quality perception are the common forces driving the installation of machine-vision systems in this and many other automotive inspection applications.

Proper Position

The key requirement of fuse-block inspection is to verify that all fuses have been inserted in their correct positions. Initially fuse recognition on the basis of color appears simple. However, examination of real fuses with their non-uniform color, shadows, glints etc. leads to the realization that the solution is not trivial. Further complications arise when fuses with dissimilar ratings have very similar colors, another reality that must be dealt with. In the application displayed in Figure 1, the close color similarity between the yellowish 20-ampere and the brownish 5-ampere fuses present significant problems for many color based machine vision systems.

Furthermore, other artifacts are co-located within the color field of each fuse; they include the ends of the embedded metal contacts and the imprinted numerals, which generally have different colors from that of the identifying fuse color. Field-experience has demonstrated that these artifacts can cause difficult recognition problems for color systems that rely on traditional thresholding and distribution matching algorithms extrapolated from gray-scale imaging experience.

Successful implementation of a robust color-based machine-vision system demands the careful selection of the incoming illumination and optics, the inspection algorithms, and the digital color camera. Once the proper algorithm has been selected, problems can still arise based on the stability and spectral properties of the incoming illumination, and on the relative stability of the three independent output channels associated with the color camera. We have found that a single chip color camera is more than sufficient to perform most of these type color applications. For these fuse block applications, the TK-1070U manufactured by JVC is utilized because of its superior channel-to-channel stability.

Color Techniques

Color is derived from a complex combination of incoming illumination, material interaction, and detection parameters. Because most modern automotive fuses are color-coded to facilitate human recognition, color-based machine vision provides an obvious method to automate correct fuse-placement verification. The techniques of color-based fuse assembly inspection can be readily applied to a variety of other color-based machine vision applications.

The measurement or determination of color can be made in various ways and result in a diverse set of parameters. The effectiveness of color-based recognition techniques varies greatly depending on the application and the expected results. One successful method for performing fuse-block inspections and similar color matching applications has been accomplished through joint efforts using WAY-2C (www.way2c.com) color-inspection systems. WAY-2C is based on a patented information theoretic classification method that has proven to be extremely well-suited for these fuse block inspection applications, and many other similar applications.

Software Classification Functions

Traditionally, variance minimization, correlation-function, and threshold-based techniques have been used for object recognition in gray-scale images. When used in a color-based machine-vision system, however, these techniques can prove unpredictable in their classification performance. The reason stems from the violation of key assumptions underlying these traditional approaches. The primary assumption in these techniques is that the mean value of a distribution approaches the most likely value, a condition that is not met in the vast majority of multicolored scenes (McConnell, R.K., Why some color vision systems work and some don't, *Vision, vol.15, no.3*, Machine Vision Association of the Society of Manufacturing Engineers, Dearborn, Michigan, 1999).

The violation of these assumptions can severally hamper a systems ability to properly execute the required inspection task. Other common factors that can influence the accuracy of color-based machine-vision include variations in component colors as supplied by the vendor (or multiple vendors), components with similar color (especially under certain lighting conditions), and the potential signal drift associated with many digital cameras.

Illumination

For many machine-vision applications, lighting is the most challenging part of the system design, and becomes a major factor when it comes to implementing color inspection. The uniformity and the stability of the incoming lighting are usually the common causes of unsatisfactory and unreliable performance of gray-scale machine-vision systems.

In color applications, these properties become even more important. If the inspection system is trained to a specific color, and that color drifts due to changing spectral properties of the incoming illumination, the vision system will make incorrect determinations based on the change in color due to the lighting, rather than on actual changes in the device under test. In general, when more spatially uniform, temporally stable, and spectrally pure (and stable) lighting is applied in the presence of external factors (line-voltage fluctuations, temperature changes, lamp aging, ambient lighting changes) then more reliable results are obtained from the vision system.

In addition to spectral properties, the lighting system must also illuminate the object so that all parameters of interest are distinguishable based on color distribution alone. These parameters include geometrical (lighting structure) effects and interference effects from external factors (ambient and secondary reflections). Field practice reveals that the best results for blade-type fuses are obtained when light is incident from an angle of about 45° with respect to the normal. This setup minimizes the background effects caused by the color mixing of stray and reflected light from other parts of the fuse block, and at the same time reduces glare from the front face of the fuse. This approach also allows the light to enter into the sides of the fuse and then diffusely emerge from the top, which causes the fuse to "glow" at the corresponding color.

An appropriate incident light spectral distribution is particularly important for all color-based inspections. The spectrum must be broad and balanced enough to show up any significant color differences within the device under test. A variety of white light sources are used for these applications, such as fluorescent, tungsten halogen, and metal halide. Each of these sources have their advantages and disadvantages with respect to cost, lifetime, and output power. However, the spectral outputs of these dissimilar sources are drastically different (see Figure 2). Fluorescent and metal-halide lamp technologies are both plasma-type discharge lamps, and are more difficult to regulate than are the hot filament type tungsten halogen lamps. Their associated spectra contain a combination of spectral peaks of high intensity, with backgrounds regions that have little or no output in several color bands. These missing bands can create false color representations, especially if the lamp type is changed.

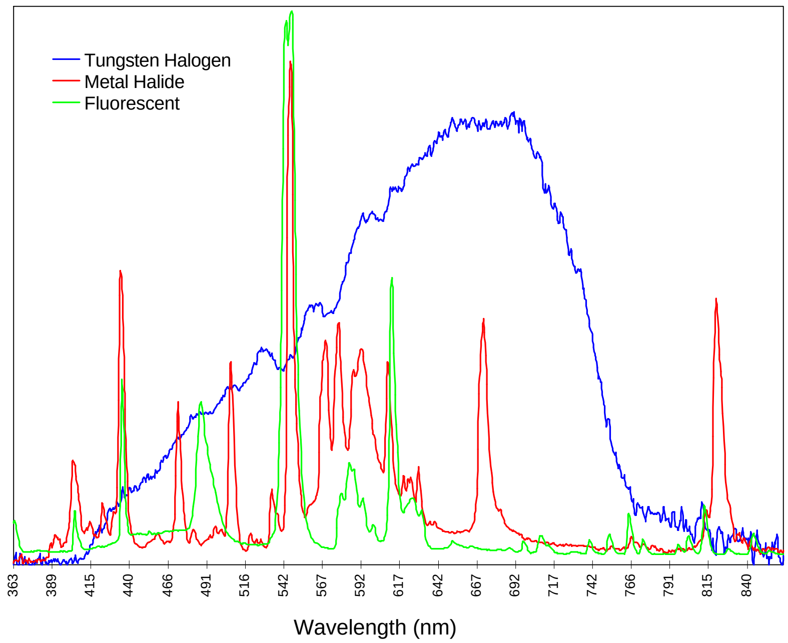

Fig 2: *Popular White Light Sources.* Relative output of several common white light generating technologies produce tremendous variation in spectral properties and stability.

The stability of the individual spectral curves for each of the three lamp technologies is also quite different. These differences can impact the long-term reliability of color-based machine-vision systems. Plasma-type lamps are less stable in spectral output, especially metal-halide lamps, which use a complex chemical composition that changes over time. When properly controlled, the tungsten-halogen lamp is the technology of choice for color-based machine-vision systems. Using sensitive, light-feedback techniques that perform real-time sampling and control of the outgoing spectral radiation ensures a constant intensity and spectral output throughout the life of the lamp.

When operated at full intensity, the output from a standard tungsten-halogen lamp has a color temperature of about 3200°K (see the red curve in Figure 3). This lamp's output is smooth and continuous with no spikes or dips in the spectra, and its 3200°K color temperature provides higher output at the red end and a lower output at the blue end.

While the light from this lamp appears white to humans, a color CCD-camera produces a red rich image. This color variation is due to the imbalance of the lamp's spectral output, and it is further exaggerated by the wavelength-dependent sensitivity of a standard silicon CCD sensor, which has stronger sensitivity to red photons than to blue photons. In many color applications, including the majority of fuse-block applications, the use of a balanced white light source is preferred in combination with an off the shelf single-chip color camera, with RGB output and good long term stability, providing an optimum balance between color quality and cost.

The green curve in Figure 3 shows the standard method for balancing the output of a 3200°K lamp. A color shifting or balancing filter, sometimes called a daylight filter, can be used to flatten the output so that it has equal intensity over the entire visible range. This filter does provide equal intensities at all wavelengths, but with a reduction in intensity of nearly 60% of the total power. The 4200°K lamp, represented by the blue curve, modifies the standard spectral output of the tungsten-halogen lamp without the use of balancing filters. While this output is not as flat as the daylight corrected spectra, it provides a much whiter light with about a 10% reduction in the overall intensity. This 4200°K lamp has become the lamp of choice for most color applications because of its satisfactory balance among spectral output, overall intensity, and lifetime.

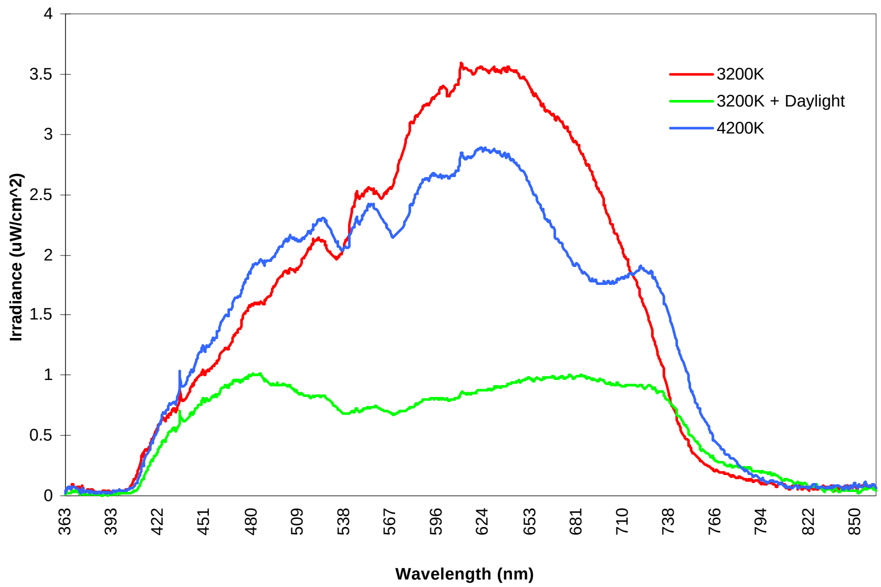

Fig 3: *Modifying the Tungsten Halogen Spectrum*. The standard Tungsten Halogen spectral output (in red) exhibits more red than blue photons. The output may be balanced with a specialty filter (green) but at the expense of intensity. The blue curve shows new lamp technology with improved red/blue balance.

White Light-Not

As in many automobile assembly and similar color inspection applications, it is not necessary to reproduce the "true" colors of the fuses, only to separate them by their appropriate group and to verify that they are in the right locations. Consequently, lighting designers have some freedom to manipulate the light source to emphasize particular portions of the spectrum that might provide the proper diagnostic information and to de-emphasize or eliminate those wavelengths that contribute less desirable information. This approach is especially useful in applications where two different fuse values have similar colors. Here, vision system designers must be careful to recognize that colors appearing almost identical to the human eye may not appear similar to a camera/algorithm based system, and vice-versa. While this does not affect camera choice, proper lighting selection can play a large role in improving system performance and reliability.

An example of this phenomenon occurs in the case of another specific class of fuse blocks (see Figure 4). This application calls for the proper determination and location of the 30-ampere-green and the 60-ampere-blue fuses. Under normal lighting, a human may find these fuses difficult to distinguish in an image, while the machine vision system easily distinguishes between them . To improve the image quality for the human viewer, the lighting solution is to use a 4200°K lamp with additional color shifting filters to move the color temperature towards 5500°K for a much bluer light. The resulting image is shown in Figure 5.

As can be seen, the change in lighting greatly improves the human ability to distinguish the fuses in the image. It turns our, however, that it makes little difference to the machine vision system's already robust ability to differentiate the 30-ampere and 60-ampere fuses! Even more surprising is that for this particular application, the machine vision system finds it more difficult to differentiate the 20-ampere and 40-ampere fuses. To the human eye, this seems to make very little sense. To clarify this phenomenon, quantitative measurements of the spectral properties of the various fuses were made.

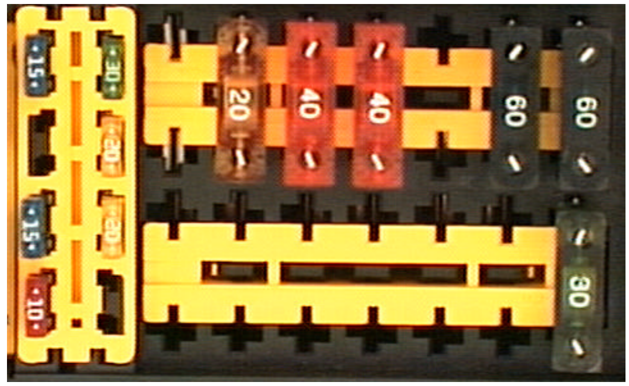

Fig 4: *Closely Matched Blue and Green Fuses* under standard Tungsten lighting.

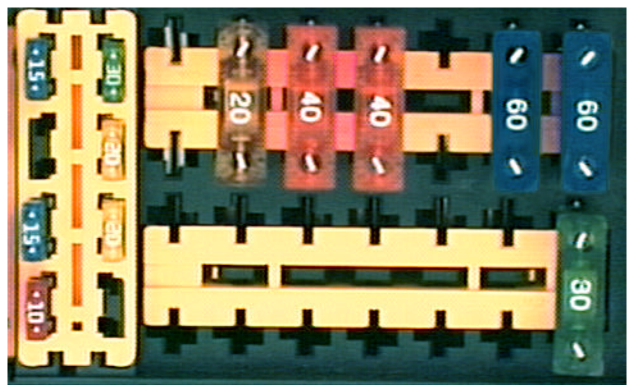

Fig 5: *Modified Spectrum to 5500°K* improves human perception of blue and green fuses.

The spectral transmission curves for each of the fuses were measured and the results are shown in Figure 6. These quantify the actual photonic distributions that the camera actually sees, assuming the use of a perfect white light source with uniform distribution from all visible wavelengths. Comparing the spectra for the blue 60-ampere fuse with the green 30-ampere fuse explains why the machine-vision system can readily discriminate between these two colored fuses, even at low saturation.

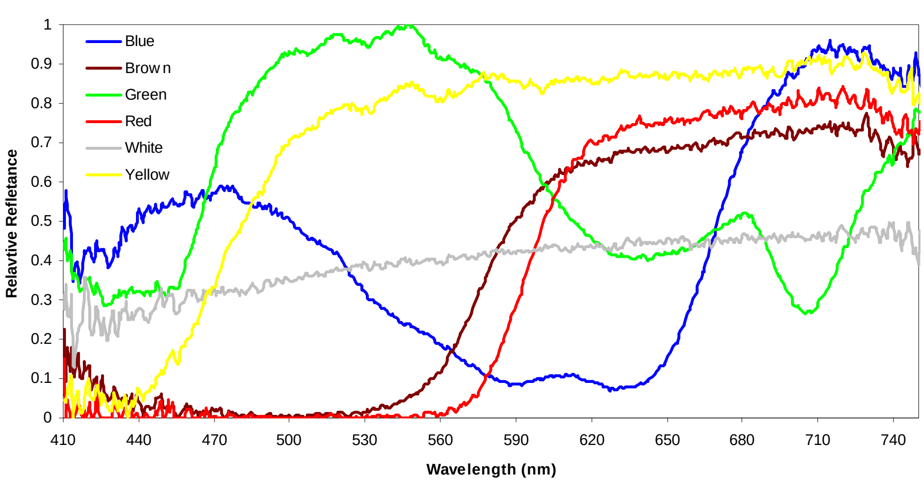

Fig 6: *Spectral Transmission Curves*

The measurement data also proved why it is more difficult for the vision system to separate the red 40-ampere and brown 20-ampere fuses. The spectral curves for these two fuses are similar, yet humans can readily distinguish them. From the data, adding blue light to these two fuses has no effect. In fact, a more reddish light would appear to enhance the characterization, which is exactly the opposite of the first visual inspection. This result highlights the fact that the proper measurement of spectral information must be used to make correct decisions regarding input illumination for maximizing the reliability of color applications.

Inspection Design

In many color-based machine-vision fuse-block-inspection applications, the color between two fuses is similar or the background carrier introduces a color that closely matches one of the fuse colors. Both conditions can create inspection problems, considering that in many cases the selected colors were random. The concept of designing for manufacturability has become an important system design consideration, and as automated inspection techniques become an ever-increasing part of the manufacturing process, the concept of designing for inspectability is paramount.

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