A Practical Guide to Machine Vision Lighting - Part III

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Overview

It is well understood that the quality and suitability 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 application note is the third 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 I and A Practical Guide to Machine Vision Lighting – Part II for further discussion of machine vision lighting design.

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1. Illumination Techniques

Illumination techniques comprise the following:

- Back Lighting
- Diffuse Lighting (also known as full bright field)
- Bright Field (actually partial bright field or directional)
- Dark Field

This document is part of the
Machine Vision Fundamentals Series

The application of some techniques requires a specific light and geometry, or relative placement of the camera, sample, and light; others do not. For example, a standard bright field bar light may also be used in dark-field mode; whereas a diffuse light is used exclusively as such.

Most manufacturers of vision lighting products also offer lights with various combinations of techniques available in the same light, and at least in the case of LED-based varieties, each of the techniques may be individually addressable. This circumstance allows for greater flexibility and also reduces potential costs when many different inspections can be accomplished in a single station, rather than two. If the application conditions and limitations of each of these lighting techniques, as well as the intricacies of the inspection environment and sample – light interactions are well-understood, it is possible to develop an effective lighting solution that meets the 3 Acceptance Criteria listed earlier.

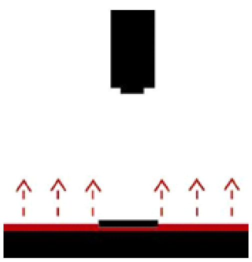

Figure 16 - Back Lighting

Back Lighting

Back lighting generates instant contrast as it creates dark silhouettes against a bright background (Figure 16). The most common uses are detecting presence / absence of holes and gaps, part placement or orientation, or for measuring objects. Often it is useful to use a monochrome light, such as red, green, or blue, with light control polarization if very precise (subpixel) edge detection becomes necessary.

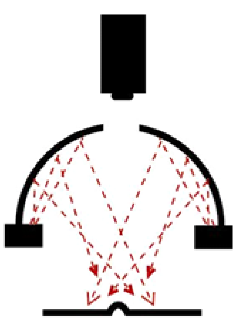

Figure 17a - Dome Diffuse

Diffuse (Full Bright Field) Lighting

Diffuse dome lights are very effective at lighting curved, specular surfaces, commonly found in the automotive industry, for example. On-axis lights work in similar fashion for flat samples, and are particularly effective at enhancing differentially angled, textured, or topographic features on relatively flat objects. To be effective, diffuse lights, particularly dome varieties, require close proximity to the sample.

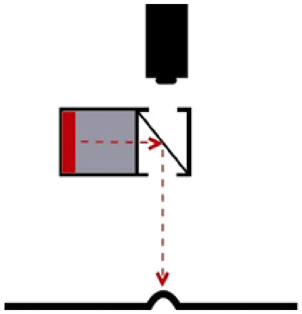

Figure 17b - On-axis Diffuse

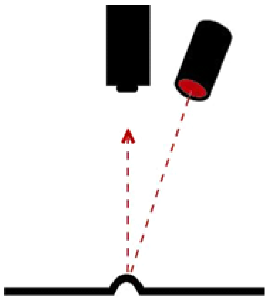

Figure 18 - Directional Bright Field

Partial Bright Field or Directional Lighting

Partial bright field lighting is the most commonly used vision lighting technique, and is the most familiar lighting we use every day, including sunlight. This type of lighting is distinguished from full bright field in that it is directional, typically from a point source, and because of its directional nature, it is a good choice for generating contrast and enhancing topographic detail. It is much less effective, however when used on-axis with specular surfaces, generating the familiar “hotspot” reflection.

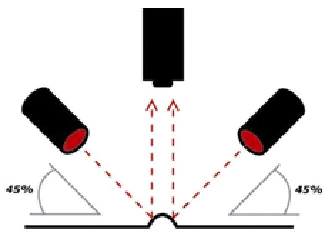

Figure 19 - Dark Field Lighting

Dark Field Lighting

Dark field lighting is perhaps the least well understood of all the techniques, although we do use these techniques in everyday life. For example, the use of automobile headlights relies on light incident at low angles on the road surface, reflecting back from the small surface imperfections, and also nearby objects.

Dark field lighting can be subdivided into circular and linear, or directional types, the former requiring a specific light head geometry design. This type of lighting is characterized by low or medium angle of light incidence, typically requiring close proximity, particularly for the circular light head varieties (Figure 19).

Bright Field vs. Dark Field

The following figures illustrate the differences in implementation and result of circular directional (partial bright field) and circular dark field lights, on a mirrored surface:

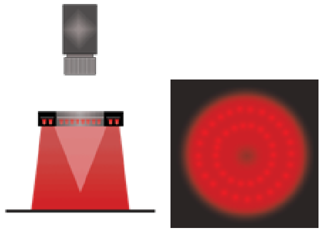

Figure 20a - Bright field image of a mirror

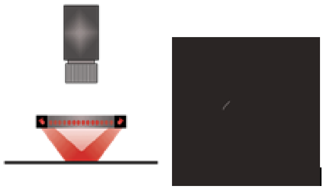

Figure 20b - Dark field image of a mirror; scratch.

Effective application of dark field lighting relies on the fact that much of the light incident on a mirrored surface that would otherwise flood the scene as a hot spot glare, is reflected away from, rather than toward the camera. The relatively small amount of light that is reflected back into the camera is what happened to catch an edge of a small feature on the surface, satisfying the “angle of reflection equals the angle of incidence” equation (See Fig 21 for another example).

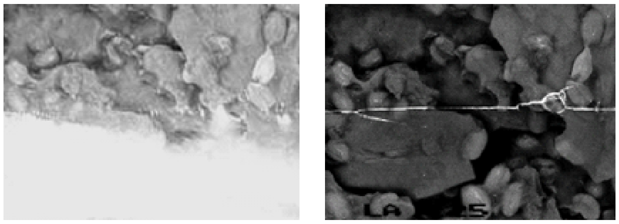

Figure 21 – Peanut Brittle Bag. Left: Under a bright field ring light. Right: Under a dark field ring light – note the seam is very visible.

2. Application Fields

Figure 22 illustrates potential application fields for the different lighting techniques, based on the two most prevalent gross surface characteristics:

1. Surface Flatness and Texture
2. Surface Reflectivity

This diagram plots surface reflectivity, divided into 3 categories, matte, mirror, and mixed versus surface flatness and texture, or topography. As one moves right and downward on the diagram, more specialized lighting geometries and structured lighting types are necessary.

As might be expected, the "Geometry Independent" section implies that relatively flat and diffuse surfaces do not require specific lighting, but rather any light technique may be effective, provided it meets all the other criteria necessary, such as working distance, access, brightness, and projected pattern, for example.

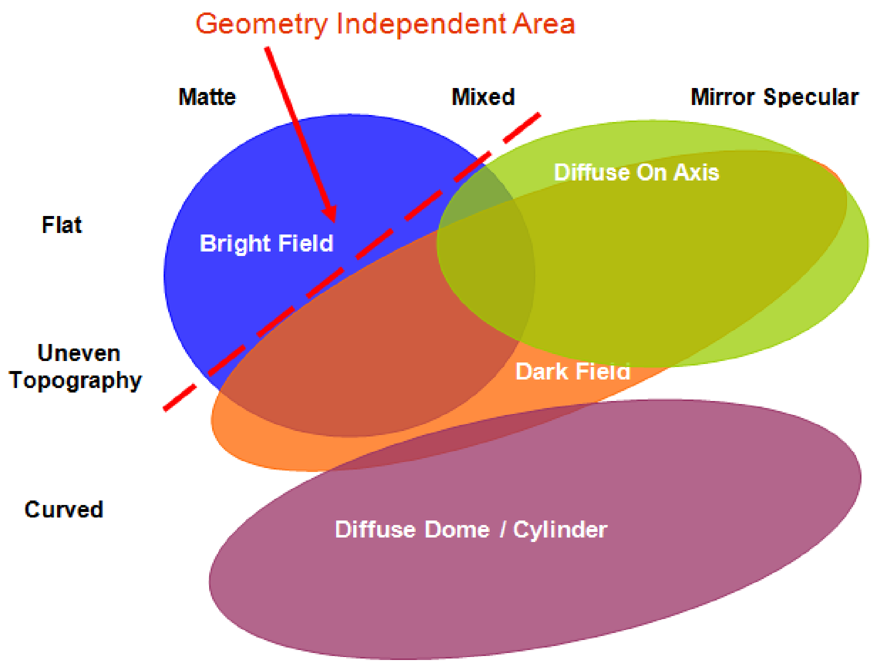

Figure 22 - Lighting Technique Application Fields - surface shape vs. surface reflectivity detail. Note that although not shown, any light technique is generally effective in the "Geometry Independent" portion of the diagram.

3. Sequence of Lighting Analysis

The following "Sequence of Lighting Analysis" assumes a working knowledge of lighting types, camera sensitivities, optics, and familiarity with illumination techniques and the four cornerstones of vision illumination. It can be used as a checklist to follow and it is by no means comprehensive, but it does provide a good working foundation for a standardized method that can be modified and/or expanded for the inspection's requirements.

1. Immediate Inspection Physical Environment
   - Physical Constraints
     - Access for camera, lens, and lighting in 3-D space (working volume)
     - The size and shape of the working volume
     - Min and max camera, lighting working distance and field-of-view
   - Part Characteristics
     - Sample stationary, moving, or indexed?
     - If moving or indexed, speeds, feeds, and expected cycle time?
     - Strobing? Expected pulse rate, on-time, and duty cycle?
     - Are there any continuous or shock vibrations?
     - Is the part presented consistently in orientation and position?
     - Any potential for ambient light contamination?
   - Ergonomics and Safety
     - Man-in-the-loop for operator interaction?
     - Safety related to strobing or intense lighting applications?
2. Sample - Light Interactions
   - Sample Surface
     - Reflectivity - Diffuse, specular, or mixed?
     - Overall Geometry - Flat, curved, or mixed?
     - Texture - Smooth, polished, rough, irregular, multiple?
     - Topography - Flat, multiple elevations, angles?
     - Light Intensity needed?
   - Composition and Color
     - Metallic, non-metallic, mixed, polymer?
     - Part color vs. background color
     - Transparent, semi-transparent, or opque - IR transmission?
     - UV dye, or fluorescent polymer?
   - Light Contamination
     - Ambient contribution from overhead or operator station lighting?
     - Light contamination from another inspection station?
     - Light contamination from the same inspection station?
3. What are the features of interest?
4. Applying the Four Cornerstones of Lighting

- Light - Camera - Sample Geometry issues
- Light pattern issues
- Color differences between sample and background
- Filters for short, long, or band pass applications, including polarization

5. Applying the Lighting Techniques and Types Knowledge, including Inten
   - Fluorescent vs. Quartz-Halogen vs. LED vs. others
   - Bright field, dark field, diffuse, back lighting
   - Vision camera and sensor quantum efficiency and spectral range

4. Summary

It is important to understand that this level of in-depth analysis can and often does result in seemingly contradictory directions, and a compromise is necessary. For example, detailed sample – light interaction analysis might point to the use of the dark field lighting technique, but the inspection environment analysis indicates that the light must be remote from the part. In this instance, a more intense linear bar light(s), oriented in dark field configuration may create the desired contrast, but perhaps require more image post processing.

Finally, no matter the level of analysis, and understanding, there is quite often no substitute for actually testing the 2 or 3 light types and techniques first on the bench, then in actual floor implementation whenever possible. And it is advantageous when designing the vision inspection and parts handling / presentation from scratch, to get the lighting solution in place first, then build the remainder of the inspection around the lighting requirements.

The ultimate objective of this form of detailed analysis and application of what might be termed a “tool box” of lighting types, techniques, tips, and often acquired “tricks” is simply to arrive at an optimal lighting solution – one that takes into account and balances issues of ergonomics, cost, efficiency, and consistent application. This frees the integrator and developer to better direct their time, effort, and resources – items better used in other critical aspects of vision system design, testing, and implementation.

5. Further Reading

- “Machine Vision and Lighting”, Nello Zuech, President, Vision Systems International, Consultancy
- “The Fundamentals: Getting Started with Machine Vision”, Valerie Bolhouse, Automation Systems Specialist, Ford Motor Company

6. Related Links

Return to Part I or Part II to learn more about machine vision lighting concepts and theories. Part I introduces concepts important to machine vision lighting systems. Part II introduces factors to consider when designing a machine vision lighting system.

- A Practical Guide to Machine Vision Lighting – Part I
- A Practical Guide to Machine Vision Lighting – Part II
- Products and Services: Machine Vision