Image Analysis and Processing

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Overview

After you have set up your imaging system and acquired images, you can analyze and process your images to extract valuable information about the objects under inspection.

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1. Image Analysis

Image analysis combines techniques that compute statistics and measurements based on the gray-level intensities of the image pixels. You can use the image analysis functions to determine whether the image quality is good enough for your inspection task. You can also analyze an image to understand its content and to decide which type of inspection tools to use t handle your application. Image analysis functions also provide measurements you can use to perform basic inspection tasks such as presence or absence verification.

Common tools you can use for image analysis include histograms, line profiles, and intensity measurements.

Histogram

A histogram counts and graphs the total number of pixels at each grayscale level. Use the histogram to determine if the overa intensity in the image is suitable for your inspection task. From the histogram, you can tell whether the image contains distinct regions of a certain gray-level value. Based on the histogram data, you can adjust your image acquisition conditions to acquir higher quality images.

You can detect two important criteria by looking at the histogram:

- Underexposure or saturation – too little light in the imaging environment leads to underexposure of the imaging sensor. To much light causes overexposure, or saturation, of the imaging sensor. Images acquired with underexposed or saturated conditions do not contain all the information that you need to inspect your object. It is important to detect these imaging conditions and correct for them during the setup of your imaging system.

  You can detect whether a sensor is underexposed or saturated by looking at the histogram. An underexposed image contains a large number of pixels with low gray-level values, as shown in Figure 1a. The low gray-level values appear as a peak at the lower end of the histogram, as shown in Figure 1b. An overexposed, or saturated image, contains a large number of pixels with very high gray-level values, as shown in Figure 2a. This condition is represented by a peak at the upper end of the histogram, as shown in Figure 2b.

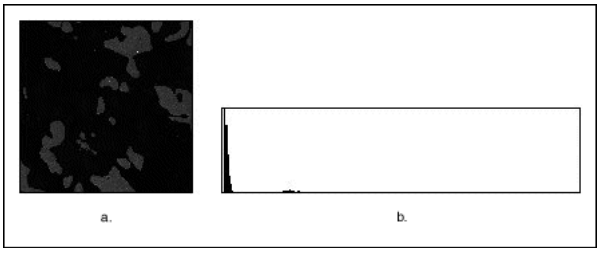

Figure 1. An Underexposed Image and Histogram

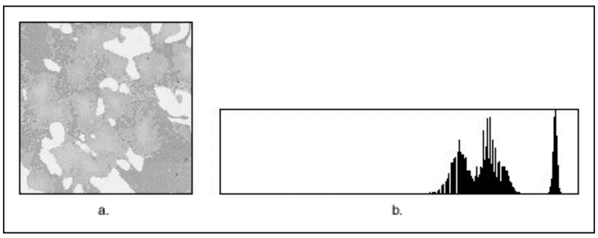

Figure 2. An Overexposed Image and Histogram

- Lack of contrast – a widely used type of imaging application involves inspecting and measuring (counting) objects of interest in a scene. A strategy to separate the objects from the background relies on a difference in the intensities of both, for example, bright particles and a darker background. The analysis of the histogram in Figure 3b reveals that Figure 3a has two or more well-separated intensity populations. Adjust your imaging setup until the histogram of your acquired images has the contrast required by your application.

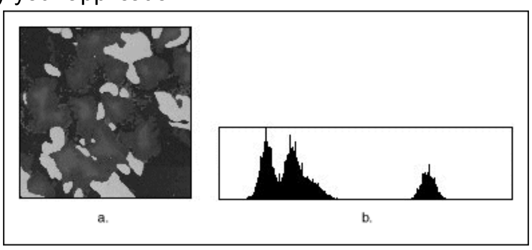

Figure 3. A Grayscale Image and Histogram

Line Profile

A line profile plots the variations of intensity along a line. It returns the grayscale values of the pixels along a line and graphs i Line profiles are helpful for examining boundaries between components, quantifying the magnitude of intensity variations, and detecting the presence of repetitive patterns.

The peaks and valleys of a line profile represent increases and decreases of the light intensity along the line selected in the image. Their width and magnitude are proportional to the size and intensity of their related regions. Figure 4 shows how a bright object with uniform intensity appears in the profile as a plateau. The higher the contrast between an object and its surrounding background, the steeper the slopes of the plateau. Noisy pixels, on the other hand, produce a series of narrow peaks.

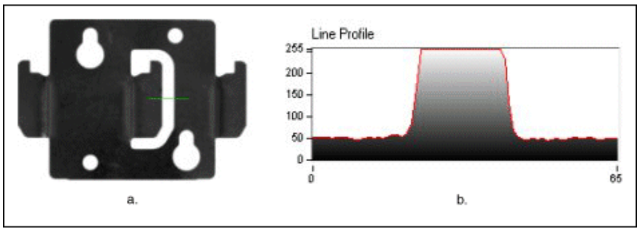

Figure 4. A Line and Corresponding Line Profile

Intensity Measurements

Intensity measurements measure the grayscale statistics in an image or regions in an image. You can use intensity measurements to perform such tasks as measuring the average intensity value in a region of the image to determine the presence or absence of a part or a defect in a part. Typical intensity measurements include the following:

- Minimum intensity value
- Maximum intensity value
- Mean intensity value
- Standard deviation of the intensity values

2. Image Processing

Using the information you gathered from analyzing your image, you may want to improve the quality of your image for inspection. You can improve the image by removing noise, highlighting features in which you are interested, and separating the object of interest from the background. Tools you can use to improve your image include lookup tables, spatial filters, grayscale morphology, and frequency-domain processing.

Lookup Tables

A lookup table (LUT) transformation converts grayscale values in the source image into other grayscale values in the transformed image. Use LUT transformations to improve the contrast and brightness of an image by modifying the dynamic intensity of regions with poor contrast. Typically, you apply LUT transformations to highlight image details in areas containing significant information at the expense of other areas.

Spatial Filters

Spatial filters improve the image quality by removing noise and smoothing, sharpening, and transforming the image. IMAQ Vision comes with many already-defined filters, such as Gaussian filters for smoothing images; Laplacian filters for highlightin image details; Median and Nth Order filters for noise removal; and Prewitt, Roberts, and Sobel filters for edge detection. You can also define your own custom filter by specifying your own filter coefficients.

Grayscale Morphology

Morphological transformations extract and alter the structure of particles in an image. You can use grayscale morphology functions to do the following:

- Filter or smooth the pixel intensities of an image
- Alter the shape of regions by expanding bright areas at the expense of dark areas and vice versa
- Remove or enhance isolated features, such as bright pixels on a dark background
- Smooth gradually varying patterns and increase the contrast in boundary areas

Applications include noise filtering, uneven background correction, and gray-level feature extraction. You can also use grayscale morphological transformations to enhance non-distinct features before thresholding the image in preparation for blo analysis.

Grayscale morphological transformations compare a pixel to those pixels surrounding it. They change the shape of particles b processing each pixel based on its number of neighbors and the values of those neighbors. A neighbor is a pixel whose value affects the values of nearby pixels during certain image processing functions. Morphological transformations use a 2D binary mask called a structuring element to define the size and effect of the neighborhood on each pixel, controlling the effect of the binary morphological functions on the shape and the boundary of a particle.

Frequency-Domain Processing

Most image processing is performed in the spatial domain. However, you may want to process an image in the frequency domain to remove unwanted frequency information before you analyze and process the image as you normally would. Use a fast Fourier transform (FFT) to convert an image into its frequency domain.

An image can have extraneous noise, such as periodic stripes, introduced during the digitization process. In the frequency domain, the periodic pattern is reduced to a limited set of high spatial frequencies. Also, the imaging setup may produce nonuniform lighting of the field of view, which results in an image with a light drift superimposed on the information you want to analyze. In the frequency domain, the light drift appears as a limited set of low frequencies around the average intensity of the image (DC component). You can use algorithms working in the frequency domain to isolate and remove these unwanted frequencies from your image. Truncating these particular frequencies and converting the filtered FFT image back to the spatial domain produces a new image in which the noise has disappeared, while the overall features remain.

3. Blob Analysis

A blob (binary large object) is an area of touching pixels with the same logical state. All pixels in an image that belong to a blob are in a foreground state. All other pixels are in a background state. In a binary image, pixels in the background have values equal to zero while every nonzero pixel is part of a binary object.

You can use blob analysis to detect blobs in an image and make selected measurements of those blobs.

Blob analysis consists of a series of processing operations and analysis functions that produce information about any 2D shape in an image.

Use blob analysis when you are interested in finding blobs whose spatial characteristics satisfy certain criteria. In many applications where computation is time-consuming, you can use blob analysis to eliminate blobs that are of no interest based on their spatial characteristics, and keep only the relevant blobs for further analysis.

You can use blob analysis to find statistical information-such as the size of blobs or the number, location, and presence of blob regions. With this information, you can perform many machine vision inspection tasks, such as detecting flaws on silicon wafers, detecting soldering defects on electronic boards, or Web inspection applications such as finding structural defects on wood planks or detecting cracks on plastics sheets. You can also locate objects in motion control applications when there is significant variance in part shape or orientation.

In applications where there is a significant variance in the shape or orientation of an object, blob analysis is a powerful and flexible way to search for the object. You can use a combination of the measurements obtained through blob analysis to define a feature set that uniquely defines the shape of the object.

Thresholding

Thresholding enables you to select ranges of pixel values in grayscale and color images that separate the objects under consideration from the background. Thresholding converts an image into a binary image, with pixel values of 0 or 1. This process works by setting to 1 all pixels whose value falls within a certain range, called the threshold interval, and setting all other pixel values in the image to 0. Figure 5a shows a grayscale image, and 5b shows the same image after thresholding.

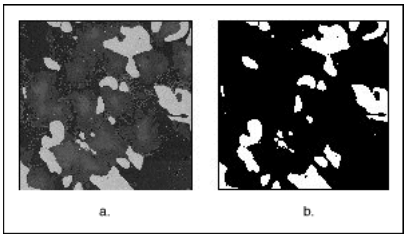

Figure 5. An Image Before and After Thresholding

Binary Morphology

Binary morphological operations extract and alter the structure of particles in a binary image. You can use these operations during your inspection application to improve the information in a binary image before making particle measurements, such as the area, perimeter, and orientation. You can also use these transformations to observe the geometry of regions and to extract the simplest forms for modeling and identification purposes.

Because thresholding is a subjective process, the resulting binary image may contain unwanted information, such as noise particles, particles touching the border of images, particles touching each other, and particles with uneven borders. By affecting the shape of particles, morphological functions can remove this unwanted information, thus improving the information in the binary image.

Primary Binary Morphology

Primary morphological operations work on binary images to process each pixel based on its neighborhood. Each pixel is set either to 1 or 0, depending on its neighborhood information and the operation used. These operations always change the overall size and shape of the particles in the image.

Use the primary morphological operations for expanding or reducing particles, smoothing the borders of objects, finding the external and internal boundaries of particles, and locating particular configurations of pixels.

Advanced Binary Morphology

The advanced morphology operations are built upon the primary morphological operations and work on particles as opposed to pixels in the image. Each of the operations has been developed to perform a specific operation on the particles in a binary image.

Use the advanced morphological operations for filling holes in particles, removing particles that touch the border of the image, remove unwanted small and large particles, separate touching particles, finding the convex hull of particles, and more.

Particle Measurements

After you create a binary image and improve it, you can make up to 50 particle measurements. With these measurements you can determine the location of blobs and their shape features. You can use these features to classify or filter the particles based on one or many measurements. For example, you can filter out particles whose areas are less than x pixels.

4. Machine Vision

The most common machine vision inspection tasks are detecting the presence or absence of parts in an image and measurin the dimensions of parts to see if they meet specifications. Measurements are based on characteristic features of the object represented in the image. Image processing algorithms traditionally classify the type of information contained in an image as edges, surfaces and textures, or patterns. Different types of machine vision algorithms leverage and extract one or more type of information.

Edge Detection

Edge detectors and derivative techniques, such as rakes, concentric rakes, and spokes, locate the edges of an object with high accuracy. An edge is a significant change in the grayscale values between adjacent pixels in an image. You can use the location of the edge to make measurements, such as the width of the part. You can use multiple edge locations to compute such measurements as intersection points, projections, and circle or ellipse fits.

Edge detection is an effective tool for many machine vision applications. Edge detection provides your application with information about the location of the boundaries of objects and the presence of discontinuities. Use edge detection in the following three applications areas – gauging, detection, and alignment.

Gauging

Use gauging to make critical dimensional measurements such as lengths, distances, diameters, angles, and counts to determine if the product under inspection is manufactured correctly. The component or part is either classified or rejected, depending on whether the gauged parameters fall inside or outside of the user-defined tolerance limits.

Figure 6 shows how a gauging application uses edge detection to measure the length of the gap in a spark plug.

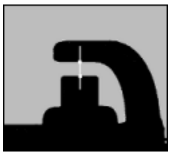

Figure 6. Using Edge Detection to Measure the Gap Between Spark Plug Electrodes

Detection

The objective of detection applications is to determine if a part is present or absent using line profiles and edge detection. An edge along the line profile is defined by the level of contrast between background and foreground and the slope of the transition. Using this technique, you can count the number of edges along the line profile and compare the result to an expected number of edges. This method offers a less numerically intensive alternative to other image processing methods such as image correlation and pattern matching.

Figure 7 shows a simple detection application in which the number of edges detected along the search line profile determines if a connector has been assembled properly. The detection of eight edges indicates that there are four wires and the connectc passes inspection, as shown in Figure 7a. Any other edge count indicates that the connector was not assembled correctly, as shown in Figure 7b.

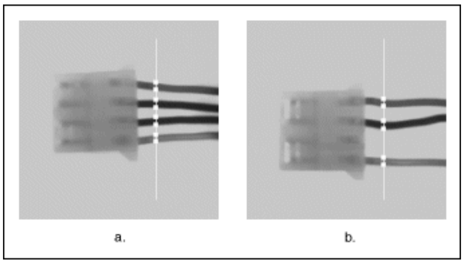

Figure 7. Using Edge Detection to Detect the Presence of a Part

You can also use edge detection to detect structural defects, such as cracks, or cosmetic defects, such as scratches on a par If the part is of uniform intensity, these defects show up as sharp changes in the intensity profile. Edge detection identifies these changes.

Alignment

Alignment determines the position and orientation of a part. In many machine vision applications, the object that you want to inspect may be at different locations in the image. Edge detection finds the location of the object in the image before you perform the inspection, so that you can inspect only the regions of interest. The position and orientation of the part can also b used to provide feedback information to a positioning device, such as a stage.

Figure 8 shows an application that detects the left edge of a disk in the image. You can use the location of the edges to determine the orientation of the disk. Then you can use the orientation information to position the regions of inspection properly.

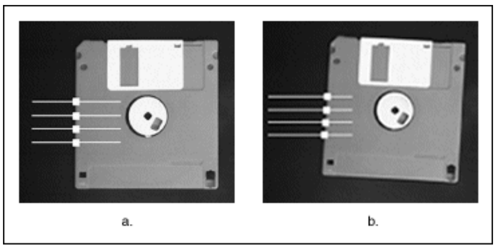

Figure 8. Using Edge Detection to Position a Region of Inspection

Pattern Matching

Pattern matching locates regions of a grayscale image that match a predetermined template. Pattern matching finds template matches regardless of poor lighting, blur, noise, shifting of the template, or rotation of the template.

Use pattern matching to quickly locate known reference patterns, or fiducials, in an image. With pattern matching you create a model or template that represents the object for which you are searching. Then your machine vision application searches for the model in each acquired image, calculating a score for each match. The score relates how closely the model matches the pattern found.

Pattern matching algorithms are some of the most important functions in image processing because of their use in varying applications. You can use pattern matching in the following three general applications – alignment, gauging, and inspection.

Alignment

Alignment determines the position and orientation of a known object by locating fiducials. Use the fiducials as points of reference on the object.

Gauging

Use pattern matching to locate the object you want to gauge. Then measure lengths, diameters, angles, and other critical dimensions. If the measurements fall outside set tolerance levels, the component is rejected.

Inspection

Use pattern matching to detect simple flaws, such as missing parts or unreadable printing.

Dimensional Measurements

You can use dimensional measurement, or gauging tools, in IMAQ Vision to obtain quantifiable, critical distance measurements. Typical measurements include the distance between points; the angle between two lines represented by three or four points; the best line, circular, or elliptical fits; and the areas of geometric shapes-such as circles, ellipses, and polygons that fit detected points.

Color Inspection

Color can simplify a monochrome visual inspection problem by improving contrast or separating the object from the background. Color inspection involves three areas: color matching, color location, and color pattern matching.

Color Matching

Color matching quantifies which colors and how much of each color exist in a region of an image and uses this information to check if another image contains the same colors in the same ratio.

Use color matching to compare the color content of an image or regions within an image to reference color information. With color matching you create an image or select regions in an image that contain the color information you want to use as a reference. The color information in the image may consist of one or more colors. The machine vision software then learns the 3D color information in the image and represents it as a 1D color spectrum. Your machine vision application compares the color information in the entire image or regions in the image to the learned color spectrum, calculating a score for each region. The score relates how closely the color information in the region matches the information represented by the color spectrum.

You can use color matching in applications such as color identification, color inspection, and other applications that require the comparison of color information to make decisions.

Figure 9 shows an example of a tile identification application. Figure 9a shows a tile that needs to be identified. Figure 9b shows a set of reference tiles and their color matching scores obtained during color matching.

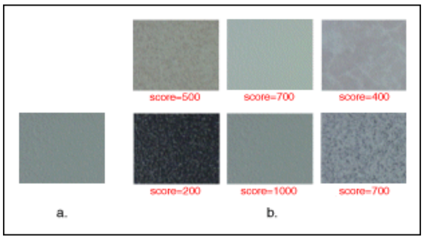

Figure 9. Using Color Matching to Identify Tiles

Color Location

Use color location to quickly locate known color regions in an image. With color location, you create a model or template that represents the colors that you are searching. Your machine vision application then searches for the model in each acquired image and calculates a score for each match. The score indicates how closely the color information in the model matches the color information in the regions found.

Color location algorithms provide a quick way to locate regions in an image with specific colors. Use color location when your application:

- Requires the location and the number of regions in an image with their specific color information
- Relies on the cumulative color information in the region, instead of how the colors are arranged in the region
- Does not require the orientation of the region
- Does not require the location with subpixel accuracy

The color location tools in IMAQ Vision measure the similarity between an idealized representation of a feature, called a model, and a feature that may be present in an image. A feature for color location is defined as a region in an image with specific colors.

Use color location in inspection, identification, and sorting applications.

Figure 10 shows a candy sorting application. Using color templates of the different candies in the image, color location quickly locates the positions of the different candies.

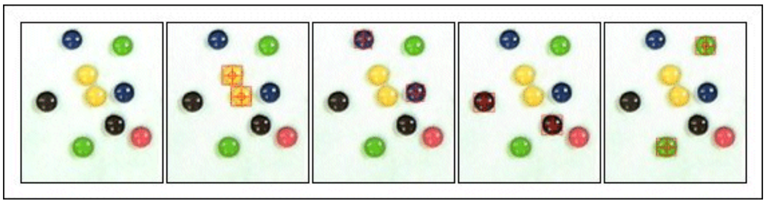

Figure 10. Using Color Location to Sort Candy

Color Pattern Matching

Use color pattern matching to quickly locate known reference patterns, or fiducials, in a color image. With color pattern matching, you create a model or template that represents the object for which you are searching. Then your machine vision application searches for the model in each acquired image, calculating a score for each match. The score indicates how closely the model matches the color pattern found. Use color pattern matching to locate reference patterns that are fully described by the color and spatial information in the pattern.

Use color pattern matching if:

- The object you want to locate contains color information that is very different from the background, and you want to find the location of the object in the image very precisely. For these applications, color pattern matching provides a more accurate solution than color location because it uses shape information during the search phase.

  Figure 11 shows the difference between color location and color pattern matching. Figure 11a is the template image of a resistor that the algorithms are searching for in the inspection images. Although color location, shown in Figure 11b, finds the resistors, the matches are not very accurate because they are limited to color information. Color pattern matching uses color matching first to locate the objects and then uses pattern matching to refine the locations, providing more accurate results, as shown in Figure 11c.

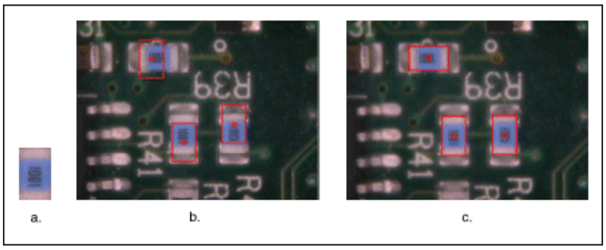

Figure 11. Using Color Pattern Matching to Accurately Locate Resistors

- The object you want to locate has grayscale properties that are very difficult to characterize or that are very similar to other objects in the search image. In such cases, grayscale pattern matching may not give accurate results. If the object has some color information that differentiates it from the other objects in the scene, color provides the machine vision software with the additional information to locate the object.

  Figure 12 shows the advantage of using color information when locating color-coded fuses on a fuse box. Figure 12a shows a grayscale image of the fuse box. In this image, the grayscale pattern matching tool has difficulty clearly differentiating between 20 A fuses and 25 A fuses because of similar grayscale intensities and the translucent nature of the fuses. In Figure 12b, color helps to separate the fuses. The addition of color helps to improve the accuracy and reliability of the pattern matching tool.

Figure 12. Using Color Pattern Matching to Accurately Identify Objects

Color pattern matching is the key to many applications. Color pattern matching provides your application with information about the number of instances and location of the template within an image. Use color pattern matching in the following three general applications – gauging, inspection, and alignment.