

IMAQ™

IMAQ Vision for LabVIEW User Manual

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Conventions

The following conventions are used in this manual:

» The » symbol leads you through nested menu items, dialog box options, and LabVIEW function palettes to a final action. For example, a VI name followed by the sequence **Vision Utilities»Image Management** directs you to look for the VI in the **Image Management** subpalette of the **Vision Utilities** function palette.



This icon denotes a note, which alerts you to important information.

bold Bold text denotes items that you must select or click on in the software, such as menu items and dialog box options. Bold text also denotes parameter names.

italic Italic text denotes variables, emphasis, a cross reference, or an introduction to a key concept. This font also denotes text that is a placeholder for a word or value that you must supply.

`monospace` Text in this font denotes text or characters that you should enter from the keyboard, sections of code, programming examples, and syntax examples. This font is also used for the proper names of disk drives, paths, directories, programs, subprograms, subroutines, device names, functions, operations, variables, filenames and extensions, and code excerpts.

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Appendix A Technical Support Resources

Glossary

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Introduction to IMAQ Vision

This chapter describes the IMAQ Vision for LabVIEW software and associated software products, discusses the documentation and examples available, outlines the IMAQ Vision palette organization, and lists the steps to making a machine vision application.



Note For information about the system requirements and installation procedure for IMAQ Vision for LabVIEW, see the *IMAQ Vision for LabVIEW Release Notes* that came with your software.

About IMAQ Vision

IMAQ Vision for LabVIEW is a library of LabVIEW VIs that you can use to develop machine vision and scientific imaging applications. National Instruments also offers IMAQ Vision for Measurement Studio, which includes the same imaging functions for LabWindows/CVI and other C development environments and includes ActiveX controls for Visual Basic. IMAQ Vision Builder, another software product from National Instruments, allows you to prototype your application strategy quickly without having to do any programming. You can also generate the LabVIEW 6.0 diagram corresponding to your prototyped solution with IMAQ Vision Builder 6.0.

Documentation and Examples

In addition to this manual, several documentation resources are available to help you create your vision application:

- *IMAQ Vision Concepts Manual*—If you are new to machine vision and imaging, read this manual to understand the concepts behind IMAQ Vision.
- IMAQ Vision for LabVIEW online reference—If you need information about IMAQ Vision palettes or individual IMAQ Vision VIs while creating your application, refer to this help file. Access this file by selecting **Help»IMAQ Vision** from within LabVIEW.

- Example programs—If you want examples of how to create specific applications, go to `LabVIEW\Examples\Vision` or see the help file at **Help»Search Vision Examples** from within LabVIEW.
- Application Notes—If you want to know more about advanced IMAQ Vision concepts and applications, refer to the Application Notes located on the National Instruments Web site at `ni.com/appnotes.nsf/`
- NI Developer Zone (NIDZ)—If you want even more information about developing your vision application, visit the NI Developer Zone at `ni.com/zone`. The NI Developer Zone contains example programs, tutorials, technical presentations, the Instrument Driver Network, a measurement glossary, an online magazine, a product advisor, and a community area where you can share ideas, questions, and source code with vision developers around the world.



Note This document references many VIs from the IMAQ Vision function palette. If you have difficulty finding a VI, use the search capability of the LabVIEW 6.0 VI browser.

IMAQ Vision Function Palettes

IMAQ Vision for LabVIEW is organized into three main function palettes: Vision Utilities, Image Processing, and Machine Vision. This section describes these palettes and their subpalettes.

Vision Utilities



The Vision Utilities functions allow you to manipulate and display images in IMAQ Vision.



- Image Management—A group of VIs that manage images. Use these VIs to create and dispose images, set and read attributes of an image (such as its size and offset), and copy one image to another. You can also use some of the advanced VIs to define the border region of an image and access the pointer to the image data.



- Files—A group of VIs that read images from files, write images to files in different file formats, and get information about the image contained in a file.



- Display—A group of VIs that control the display of images in external image windows. Use these VIs to get and set window attributes, such as size, position, and zoom factor, assign color palettes to image windows, and setup and use image browsers.



- **Region of Interest**—A group of VIs that manage regions of interest (ROIs) in image windows. Use these VIs to setup and use different drawing tools to interactively select ROIs on image windows, programmatically define ROIs, detect draw events, retrieve information about the ROIs drawn on the image window, and convert ROIs to and from image masks.



- **Image Manipulation**—A group of VIs that modify the spatial content of images. Use these VIs to resample an image, extract parts of an image, and rotate, shift, and unwrap images. This subpalette also contains VIs that copy images to and from the clipboard.



- **Pixel Manipulation**—A group of VIs that read and modify individual pixels in an image. Use these VIs to read and set pixel values in an image or along a row or column in an image, fill the pixels in an image with a particular value, and convert an image to and from a 2D LabVIEW array.



- **Overlay**—A group of VIs that overlay graphics on an image window without altering the pixel values of the image. Use these VIs to overlay the results of your inspection application onto the images you inspect.



- **Calibration**—A group of VIs that spatially calibrate an image to take accurate, real-world measurements regardless of camera perspective or lens distortion. Use these VIs to set a simple calibration or to let IMAQ Vision automatically learn the calibration data from a grid image. Then use the VIs to convert pixel coordinates to real-world coordinates for simple measurements or correct the image for shape measurements, such as blob analysis.



- **Color Utilities**—A group of VIs that access data from color images. Use these VIs to extract different color planes from an image, replace the planes of a color image with new data, convert a color image to and from a 2D array, read and set pixel values in a color image, and convert pixel values from one color space to another.

Image Processing



Use the Image Processing functions to analyze, filter, and process images in IMAQ Vision.



- **Processing**—A group of VIs that process grayscale and binary images. Use the VIs in this subpalette to convert a grayscale image into a binary image using different thresholding techniques. You can also use these VIs to transform images using predefined or custom lookup tables, change the contrast information in the image, and invert the values in an image.



- **Filters**—A group of VIs that filter an image to enhance the information in the image. Using these VIs you can smooth your image, remove noise, and highlight or enhance edges in the image. You can use a predefined convolution kernel or create custom convolution kernels.



- **Morphology**—A group of VIs that perform morphological operations on an image. Some of these VIs perform basic morphological operations, such as dilation and erosion, on grayscale and binary images. Other VIs improve the quality of binary images by filling holes in particles, removing particles that touch the image border, removing small particles, and removing unwanted particles based on different shape characteristics of the particle. Another set of VIs in this subpalette separate touching particles, find the skeleton of particles, and detect circular particles.



- **Analysis**—A group of VIs that analyze the content of grayscale and binary images. Use these VIs to compute the histogram information and grayscale statistics of an image, retrieve pixel information and statistics along any one-dimensional profile in an image, and detect and measure particles (or blobs) in binary images.



- **Color Processing**—A group of VIs that analyze and process color images. Use these VIs to compute the histogram of color images; apply lookup tables to color images; change the brightness, contrast, and gamma information associated with a color image; and threshold a color image. Some of these VIs also compare the color information in different images or different regions in an image using a color matching process.



- **Operators**—A group of VIs that perform basic arithmetic and logical operations on images. Use some of these VIs to add, subtract, multiply, and divide an image with other images or constants. Use other VIs in this subpalette to apply logical operations—such as AND/NAND, OR/NOR, XOR/XNOR—and make pixel comparisons between an image and other images or a constant. In addition, one VI in this subpalette allows you to select regions in an image to process using a masking operation.



- **Frequency Domain**—A group of VIs that analyze and process images in the frequency domain. Use these VIs to convert an image from the spatial domain to the frequency domain using a two-dimensional Fast Fourier Transform (FFT) and convert from the frequency domain to the spatial domain using the inverse FFT. These VIs also extract the magnitude, phase, real, and imaginary planes of the complex image. In addition, these VIs allow you to convert complex images into complex 2D arrays and back. Also in this subpalette are VIs that perform basic arithmetic operations—such as addition, subtraction,

multiplication and division—between a complex image and other images or a constant. Lastly, some of these VIs allow you to filter images in the frequency domain.

Machine Vision



The IMAQ Machine Vision VIs are high-level VIs that simplify common machine vision tasks.



- **Select Region of Interest**—A group of VIs that allow you to select a region of interest tool, draw specific regions of interest in the image window, and return information about regions with very little programming.



- **Coordinate System**—A group of VIs that find a coordinate system associated with an object in an image. Use these VIs to find the coordinate system using either edge detection or pattern matching. You can then use this coordinate system to take measurements from other Machine Vision VIs.



- **Count and Measure Objects**—A VI that thresholds an image to isolate objects from the background and then finds and measures characteristics of the objects. This VI can also ignore unwanted objects in the image when making measurements.



- **Measure Intensities**—A group of VIs that measure the intensity of a pixel at a point or the statistics of pixel intensities along a line or rectangular region in an image.



- **Measure Distances**—A group of VIs that measure distances, such as the minimum and maximum horizontal distance between two vertically oriented edges or the minimum and maximum vertical distance between two horizontally oriented edges.



- **Locate Edges**—A group of VIs that locate vertical, horizontal, and circular edges.



- **Find Patterns**—This VI learns and searches for a pattern in an image.



- **Searching and Matching**—A group of VIs that create and search for patterns in grayscale and color images. This subpalette also contains a VI to search for objects with predefined shapes in binary images.



- **Caliper**—A group of VIs that find edges along different profiles in the image. Use these VIs to find edges along a line, a set of parallel lines defined inside a rectangular region (rake), a set of parallel concentric lines defined inside an annular region (concentric rake), or a set of radial lines defined inside an annular region (spoke). You can also use these VIs to find edge pairs in the image that satisfy certain criteria.



- Analytic Geometry—A group of VIs that perform analytic geometry computations on a set of points in an image. Use these VIs to fit lines, circles, and ellipses to a set of points in the image; compute the area of a polygon represented by a set of points; measure distances between points; and find angles between lines represented by points. VIs in this subpalette also perform computations, such as finding the intersection point of two lines and finding the line bisecting the angle formed by two lines.



- Instrument Readers—A group of VIs that accelerate the development of applications that require reading from seven-segment displays, meters or gauges, or one-dimensional barcodes.

Creating IMAQ Vision Applications

Figures 1-1 and 1-2 illustrate the steps for creating an application with IMAQ Vision. Figure 1-1 describes the general steps to designing a Vision application. The last step in Figure 1-1 is expanded upon in Figure 1-2. You can use a combination of the items in the last step to create your IMAQ Vision application. For more information about items in either diagram, see the corresponding chapter listed to the right of the item.



Note Diagram items enclosed with dashed lines are optional steps.

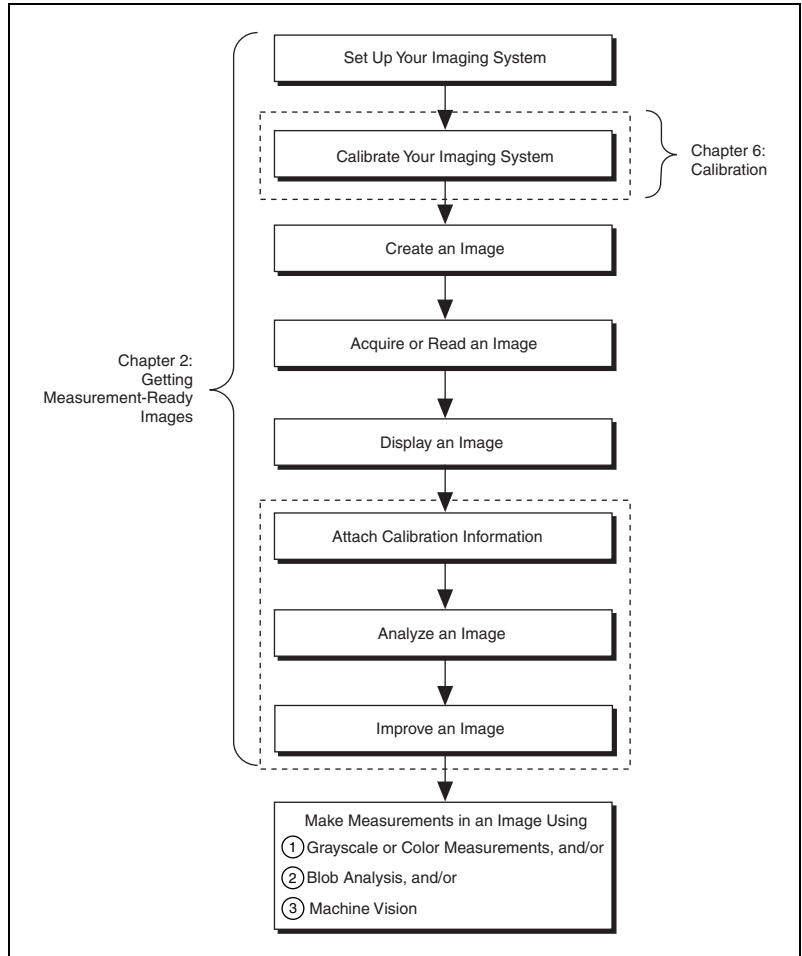


Figure 1-1. General Steps to Designing a Vision Application

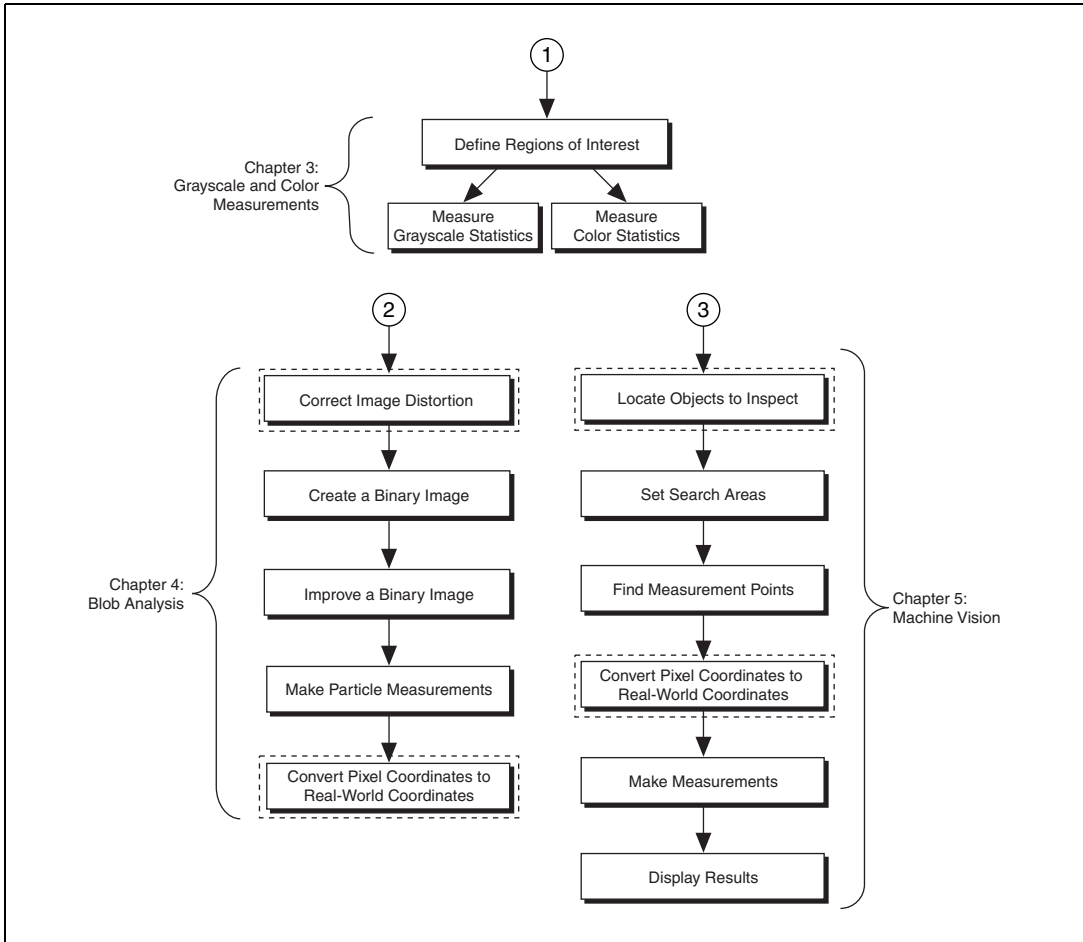


Figure 1-2. Inspection Steps for Building a Vision Application

Getting Measurement-Ready Images

This chapter describes how to set up your imaging system, acquire and display an image, analyze the image, and prepare the image for additional processing.

Set Up Your Imaging System

Before you acquire, analyze, and process images, you must set up your imaging system. The manner in which you set up your system depends on your imaging environment and the type of analysis and processing you need to do. Your imaging system should produce images with high enough quality so that you can extract the information you need from the images.

Follow the guidelines below to setup your imaging system.

1. Determine the type of equipment you need given space constraints and the size of the object you need to inspect. For more information, see Chapter 3, *System Setup and Calibration*, of the *IMAQ Vision Concepts Manual*.
 - a. Make sure your camera sensor is large enough to satisfy your minimum resolution requirement.
 - b. Make sure your lens has a depth of field high enough to keep all of your objects in focus regardless of their distance from the lens. Also, make sure your lens has a focal length that meets your needs.
 - c. Make sure your lighting provides enough contrast between the object under inspection and the background for you to extract the information you need from the image.
2. Position your camera so that it is parallel to the object under inspection. If your camera acquires images of the object from an angle, perspective errors occur. While you can compensate for these errors with software, use a parallel inspection angle to obtain the most accurate results.

3. Select an image acquisition device that meets your needs. National Instruments offers several image acquisition (IMAQ) devices, such as analog color and monochrome IMAQ devices as well as digital devices. Visit ni.com/imaq for more information about IMAQ devices.
4. Configure the driver software for your image acquisition device. If you have a National Instruments image acquisition device, configure your NI-IMAQ driver software through Measurement & Automation Explorer (MAX). Open MAX by double-clicking the Measurement & Automation Explorer icon on your desktop. For more information, see the *NI-IMAQ User Manual* and the MAX online help.

Calibrate Your Imaging System

After you set up your imaging system, you may want to calibrate your system. Calibrate your imaging system to assign real-world coordinates to pixel coordinates and compensate for perspective and nonlinear errors inherent in your imaging system.

Perspective errors occur when your camera axis is not perpendicular to the object under inspection. Nonlinear distortion may occur from aberrations in the camera lens. Perspective errors and lens aberrations cause images to appear distorted. This distortion misplaces information in an image, but it does not necessarily destroy the information in the image.

Use simple calibration if you only want to assign real-world coordinates to pixel coordinates. Use perspective and nonlinear distortion calibration if you need to compensate for perspective errors and nonlinear lens distortion. For detailed information about calibration, see Chapter 6, [Calibration](#).

Create an Image



Use the IMAQ Create VI (**Vision Utilities»Image Management**) to create an image structure and a reference to the structure for every image you want to use in your application. Assign a unique name to every image that you want to create. You can also specify the type of the image. The following image types are valid:

- 8-bit (default)
- 16-bit
- Float
- Complex

- RGB
- HSL

If you plan to use filtering or blob analysis VIs on the image, set the appropriate border size for the image. The default border size is 3.

When you create an image, IMAQ Vision creates an internal image structure to hold properties of the image, such as its name and border size. However, no memory is allocated to store the image pixels at this time. IMAQ Vision VIs automatically allocate the appropriate amount of memory when the image size is modified. For example, VIs that acquire or resample an image alter the image size, so they allocate the appropriate memory space for the image pixels. The output of IMAQ Create is a reference to the image structure. The image reference is in the form of a LabVIEW cluster. Supply this reference as an input to all subsequent IMAQ Vision functions.

Most VIs belonging to the IMAQ Vision library require an input of one or more image references. The number of image references a VI takes depends on the image processing function and the type of image you want to use.

IMAQ Vision VIs that analyze the image but do not modify the contents only require the input of one image reference. VIs that process the contents of images require a reference to the source image(s) and to a destination image.

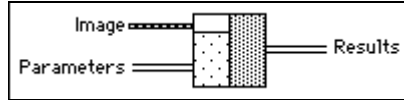
You can create multiple images by executing IMAQ Create as many times as you want, but each image you create requires a unique name. Determine the number of required images through an analysis of your intended application. The decision is based on different processing phases and your need to keep the original image (after each processing step).



At the end of your application, dispose of each image that you created using the IMAQ Dispose VI (**Vision Utilities»Image Management**)

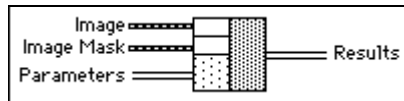
Depending on the type of function a VI performs, different combinations of input and output are possible. You can use this flexibility to decide which image to process and where to store the resulting image. If no destination image is wired, the source image is used and passed to the destination output.

The following figures show several connector panes used in IMAQ Vision.



This connector pane applies only to VIs that analyze an image and therefore do not modify either the size or contents of the image. Examples of these types of operations include particle analysis and histogram calculations.

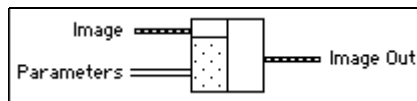
The following pane introduces an **Image Mask**.



The presence of an **Image Mask** input indicates that the processing or analysis is dependent on the contents of another image (the **Image Mask**). The only pixels in **Image** that are processed are those whose corresponding pixels in **Image Mask** are non-zero. If an **Image Mask** pixel is 0, the corresponding **Image** pixel is not changed. **Image Mask** must be an 8-bit image.

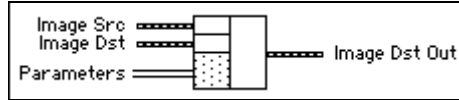
If you want to apply a processing or analysis function to the entire image, do not connect the **Image Mask** input. Connecting the same image to both inputs **Image** and **Image Mask** also gives the same effect as leaving the input **Image Mask** unconnected, except in this case the **Image** must be an 8-bit image.

The following connector pane applies to VIs performing an operation that fills an image.



Examples of this type of operation include reading a file, acquiring an image from an IMAQ device, or transforming a 2D array into an image. This type of VI can modify the size of an image.

The following connector pane applies to VIs that process an image.

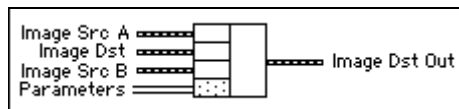


This connector is the most common type in IMAQ Vision. The **Image Src** input receives the image to process. The **Image Dst** input can receive either another image or the original, depending on your goals. If two different images are connected to the two inputs, the original **Image Src** image is not modified. As shown in the following diagrams, if the **Image Dst** and **Image Src** inputs receive the same image, or if nothing is connected to **Image Dst**, the processed image is placed into the original image, and the original image data is lost.

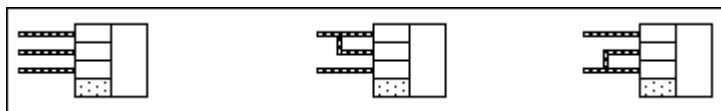


The **Image Dst** image is the image that receives the processing results. Depending on the functionality of the VI, this image can be either the same or a different image type as that of the source image. The VI descriptions in the IMAQ Vision for LabVIEW online reference include the type of image that can be connected to the **Image** inputs. The image connected to **Image Dst** will be resized to the source image size.

The following connector pane applies to VIs that perform arithmetic or logical operations between two images.



Two source images exist for the destination image. You can perform an operation between two images A and B and then either store the result in another image (**Image Dst**) or in one of the two source images, A or B. In the latter case, you can consider the original data to be unnecessary after the processing has occurred. The following combinations are possible in this pane.



In the pane on the left, the three images are all different. **Image Src A** and **Image Src B** are intact after processing and the results from this operation are stored in **Image Dst**.

In the center pane, **Image Src A** also is connected to the **Image Dst**, which therefore receives the results from the operation. In this operation, the source data for **Image Src A** is overwritten.

In the pane on the right, **Image Src B** receives the results from the operation and its source data is overwritten.

Most operations between two images require that the images have the same type and size. However, arithmetic operations can work between two different types of images (for example, 8-bit and 16-bit).

Acquire or Read an Image

After you create an image reference, you can acquire an image into your imaging system in three ways. You can acquire an image with a camera through your image acquisition device, load an image from a file stored on your computer, or convert the data stored in a 2D array to an image. VIs that acquire images, load images from file, or convert data from a 2D array automatically allocate the memory space required to accommodate the image data.

Use one of the following methods to acquire images with a National Instruments image acquisition (IMAQ) device:



- Acquire a single image using the IMAQ Snap VI (**Image Acquisition**). When you call this VI, it initializes the IMAQ device and acquires the next incoming video frame. Use this VI for low-speed or single capture applications where ease of programming is essential.
- Acquire images continually through a grab acquisition. Grab functions perform an acquisition that loops continually on one buffer. Use the grab functions for high-speed image acquisition. Use the IMAQ Grab Setup VI (**Image Acquisition**) to start the acquisition. Use the IMAQ Grab Acquire VI (**Image Acquisition**) to return a copy of the current image. Use the IMAQ Stop VI (**Image Acquisition**»**Low-Level Acquisition**) to stop the acquisition.
- Acquire a fixed number of images using the IMAQ Sequence VI (**Image Acquisition**). IMAQ Sequence acquires one image after another until it has acquired the number of images you requested. If you want to acquire only certain images, supply IMAQ Sequence

with a table describing the number of frames to skip after each acquired frame.



Note You must use the IMAQ Close VI (**Image Acquisition**) to release resources associated with the image acquisition device.



Use the IMAQ ReadFile VI (**Vision Utilities»Files**) to open and read data from a file stored on your computer into the image reference. You can read from image files stored in a standard format (BMP, TIFF, JPEG, PNG, and AIPD) or a nonstandard format you specify. In all cases, the software automatically converts the pixels it reads into the type of image you pass in.



Use the IMAQ Read Image and Vision Info VI (**Vision Utilities»Files**) to open an image file containing additional information, such as calibration information, template information for pattern matching, or overlay information. For more information about pattern matching templates and overlays, see Chapter 5, *Machine Vision*.



You can also use the IMAQ GetFileInfo VI (**Vision Utilities»Files**) to retrieve image properties—image size, pixel depth, recommended image type, and calibration units—without actually reading all the image data.



Use the IMAQ ArrayToImage VI (**Vision Utilities»Pixel Manipulation**) to convert a 2D array to an image. You can also use the



IMAQ ImageToArray VI (**Vision Utilities»Pixel Manipulation**) to convert an image to a LabVIEW 2D array.

Display an Image



Display an image in an external window using the IMAQ WindDraw VI (**Vision Utilities»Display**). You can display images in 16 different external windows. Use the IMAQ WindSetup VI (**Vision Utilities»Display**) to



configure the appearance of each external window. You can decide whether the window has scroll bars, is resizable, has a title bar, and so on.



You can also use the IMAQ WindMove VI (**Vision Utilities»Display**) to position the external image window at a particular location on your monitor.



Note Image windows are not LabVIEW panels. They are managed directly by IMAQ Vision.



You can use a color palette to display grayscale images. You can apply a color palette to the window. You can use the IMAQ GetPalette VI (**Vision Utilities»Display**) to obtain predefined color palettes. For example, if you need to display a binary image—an image containing particle regions with pixel values of 1 and a background region with pixel values of 0—apply the predefined binary palette. For more information about color palettes, see the Chapter 2, *Display*, of the *IMAQ Vision Concepts Manual*.



Note At the end of your application, you must close all open external windows using the IMAQ WindClose VI (**Vision Utilities»Display**).



Attach Calibration Information



If you want to attach the calibration information of the current setup to each image you acquire, use the IMAQ Set Calibration Info VI (**Vision Utilities»Calibration**). This VI takes in a source image containing the calibration information and a destination image that you want to calibrate. The output image is your inspection image with the calibration information attached to it. For detailed information about calibration, see Chapter 6, *Calibration*.



Note Because calibration information is part of the image, it is propagated throughout the processing and analysis of the image. Functions that modify the image size (such as geometrical transforms) void the calibration information. Use IMAQ Write Image and Vision Info (**Vision Utilities»Calibration**) to save the image and all of the attached calibration information to a file.



Analyze an Image

Once you acquire and display an image, you may want to analyze the contents of the image for the following reasons:

- To determine whether the image quality is good enough for your inspection task.
- To obtain the values of parameters that you want to use in processing functions during the inspection process.

The histogram and line profile tools can help you analyze the quality of your images.



Use the IMAQ Histogram and IMAQ Histogram VIs (**Image Processing»Analysis**) to analyze the overall grayscale distribution in the image. Use the

histogram of the image to analyze two important criteria that define the quality of an image: saturation and contrast. If your image is underexposed (does not have enough light) the majority of your pixels will have low intensity values, which appear as a concentration of peaks on the left side of your histogram. If your image is overexposed (has too much light) the majority of your pixels will have a high intensity values, which appear as a concentration of peaks on the right side of your histogram. If your image has an appropriate amount of contrast, your histogram will have distinct regions of pixel concentrations. Use the histogram information to decide if the image quality is good enough to separate objects of interest from the background.

If the image quality meets your needs, use the histogram to determine the range of pixel values that correspond to objects in the image. You can use this range in processing functions, such as determining a threshold range during blob analysis.

If the image quality does not meet your needs, try to improve the imaging conditions to get the desired image quality. You may need to re-evaluate and modify each component of your imaging setup: lighting equipment and setup, lens tuning, camera operation mode, and acquisition board parameters. If you reach the best possible conditions with your setup but the image quality still does not meet your needs, try to improve the image quality using the image processing techniques described in the [Improve an Image](#) section.



Use the IMAQ LineProfile VI (**Image Processing»Analysis**) to get the pixel distribution along a line in the image, or use the IMAQ ROIProfile VI (**Image Processing»Analysis**) to get the pixel distribution along a one-dimensional path in the image. To use a line profile to analyze your image, draw or specify a line across the boundary of an object in your image. Use IMAQ LineProfile to examine the pixel values along the line. By looking at the pixel distribution along this line, you can determine whether the image quality is good enough to provide you with sharp edges at object boundaries. Also, you can determine whether the image is noisy, and identify the characteristics of the noise.



If the image quality meets your needs, use the pixel distribution information to determine some parameters of the inspection functions you want to use. For example, use the information from the line profile to determine the strength of the edge at the boundary of an object. You can input this information into the IMAQ Edge Tool VI (**Machine Vision»Caliper**) to find the edges of objects along the line.

Improve an Image

Using the information you gathered from analyzing your image, you may want to improve the quality of your image for inspection. You can improve your image with lookup tables, filters, grayscale morphology, and Fast Fourier transforms.

Lookup Tables

Apply *lookup table* (LUT) transformations to highlight image details in areas containing significant information at the expense of other areas. A LUT transformation converts input grayscale values in the source image into other grayscale values in the transformed image. IMAQ Vision provides four VIs that directly or indirectly apply lookup tables to images:



- IMAQ MathLookup (**Image Processing»Processing**)—Converts the pixel values of an image by replacing them with values from a predefined lookup table. IMAQ Vision has seven predefined lookup tables based on mathematical transformations. For more information about these lookup tables, see Chapter 5, *Image Processing*, in the *IMAQ Vision Concepts Manual*.



- IMAQ UserLookup (**Image Processing»Processing**)—Converts the pixel values of an image by replacing them with values from a user-defined lookup table.



- IMAQ Equalize (**Image Processing»Processing**)—Distributes the grayscale values evenly within a given grayscale range. Use IMAQ Equalize to increase the contrast in images containing few grayscale values.



- IMAQ Inverse (**Image Processing»Processing**)—Inverts the pixel intensities of an image to compute the negative of the image. For example, use IMAQ Inverse before applying an automatic threshold to your image if the background pixels are brighter than the object pixels.

Filters

Filter your image when you need to improve the sharpness of transitions in the image or increase the overall signal-to-noise ratio of the image. You can choose either a lowpass or highpass filter depending on your needs.

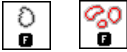


Lowpass filters remove insignificant details by smoothing the image, removing sharp details, and smoothing the edges between the objects and the background. You can use the IMAQ LowPass VI (**Image Processing»Filters**) or define your own lowpass filter with the



IMAQ Convolute VI (**Image Processing»Filters**) or IMAQ NthOrder VI (**Image Processing»Filters**).

Highpass filters emphasize details, such as edges, object boundaries, or cracks. These details represent sharp transitions in intensity value. You can define your own highpass filter with IMAQ Convolute or IMAQ NthOrder or use the IMAQ EdgeDetection VI or IMAQ CannyEdgeDetection VI (**Image Processing»Filters**). IMAQ EdgeDetection allows you to find edges in an image using predefined edge detection kernels, such as the Sobel, Prewitt, and Roberts kernels.



Convolution Filter

IMAQ Convolute allows you to use a predefined set of lowpass and highpass filters. Each filter is defined by a kernel of coefficients. Use the IMAQ GetKernel VI (**Image Processing»Filters**) to retrieve predefined kernels. If the predefined kernels do not meet your needs, define your own custom filter using a LabVIEW 2D array of floating point numbers.



Nth Order Filter

IMAQ NthOrder allows you to define a lowpass or highpass filter depending on the value of N that you choose. One specific Nth order filter, the median filter, removes speckle noise, which appears as small black and white dots. For more information about Nth order filters, see Chapter 5, *Image Processing*, of the *IMAQ Vision Concepts Manual*.

Grayscale Morphology

Perform grayscale morphology when you want to filter grayscale features of an image. Grayscale morphology helps you remove or enhance isolated features, such as bright pixels on a dark background. Use these transformations on a grayscale image to enhance non-distinct features before thresholding the image in preparation for blob analysis.

Grayscale morphological transformations compare a pixel to those pixels surrounding it. The transformation keeps the smallest pixel values when performing an erosion or keeps the largest pixel values when performing a dilation.

For more information about grayscale morphology transformations, see Chapter 5, *Image Processing*, of the *IMAQ Vision Concepts Manual*.



Use the IMAQ GrayMorphology VI (**Image Processing»Morphology**) to perform one of the following seven transformations:

- Erosion—Reduces the brightness of pixels that are surrounded by neighbors with a lower intensity. Define the neighborhood with a structuring element.
- Dilation—Increases the brightness of pixels surrounded by neighbors with a higher intensity. A dilation has the opposite effect as an erosion.
- Opening—Removes bright pixels isolated in dark regions and smooths boundaries.
- Closing—Removes dark spots isolated in bright regions and smooths boundaries.
- Proper-opening—Removes bright pixels isolated in dark regions and smooths the boundaries of regions.
- Proper-closing—Removes dark pixels isolated in bright regions and smooths the boundaries of regions.
- Auto-median—Generates simpler particles that have fewer details.

FFT

Use the Fast Fourier Transform (FFT) to convert an image into its frequency domain. In an image, details and sharp edges are associated with mid to high spatial frequencies because they introduce significant gray-level variations over short distances. Gradually varying patterns are associated with low spatial frequencies.

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 non-uniform lighting of the field of view, which produces 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. Follow these steps to obtain an image in which the unwanted pattern has disappeared but the overall features remain:



1. Use the IMAQ FFT VI (**Image Processing»Frequency Domain**) to convert an image from the spatial domain to the frequency domain. This VI computes the Fast Fourier Transform (FFT) of the image and

results in a complex image representing the frequency information of your image.



2. Improve your image in the frequency domain with a lowpass or highpass frequency filter. Specify which type of filter to use with the IMAQ ComplexAttenuate VI (**Image Processing»Frequency Domain**) or the IMAQ ComplexTruncate VI (**Image Processing»Frequency Domain**). Lowpass filters smooth noise, details, textures, and sharp edges in an image. Highpass filters emphasize details, textures, and sharp edges in images, but they also emphasize noise.
 - Lowpass attenuation—The amount of attenuation is directly proportional to the frequency information. At low frequencies, there is little attenuation. As the frequencies increase, the attenuation increases. This operation preserves all of the zero frequency information. Zero frequency information corresponds to the DC component of the image or the average intensity of the image in the spatial domain.
 - Highpass attenuation—The amount of attenuation is inversely proportional to the frequency information. At high frequencies, there is little attenuation. As the frequencies decrease, the attenuation increases. The zero frequency component is removed entirely.
 - Lowpass truncation—Specify a frequency. The frequency components above the ideal cutoff frequency are removed, and the frequencies below it remain unaltered.
 - Highpass truncation—Specify a frequency. The frequency components above the ideal cutoff frequency remain unaltered, and the frequencies below it are removed.
3. To transform your image back to the spatial domain, use the IMAQ InverseFFT VI (**Image Processing»Frequency Domain**).



Advanced Operations



The IMAQ ImageToComplexPlane VI (**Image Processing»Frequency Domain**) and IMAQ ComplexPlaneToImage VI (**Image Processing»Frequency Domain**) allow you to access, process, and update independently the magnitude, phase, real, and imaginary planes of a complex image. You can also convert a complex image to an array and back with the IMAQ ComplexImageToArray VI (**Image Processing»Frequency Domain**) and IMAQ ArrayToComplexImage VI (**Image Processing»Frequency Domain**).

Grayscale and Color Measurements

This chapter describes how to take measurements from grayscale and color images. You can make inspection decisions based on image statistics, such as the mean intensity level in a region. Based on the image statistics, you can perform many machine vision inspection tasks on grayscale or color images, such as detecting the presence or absence of components, detecting flaws in parts, and comparing a color component with a reference. Figure 3-1 illustrates the basic steps involved in making grayscale and color measurements.

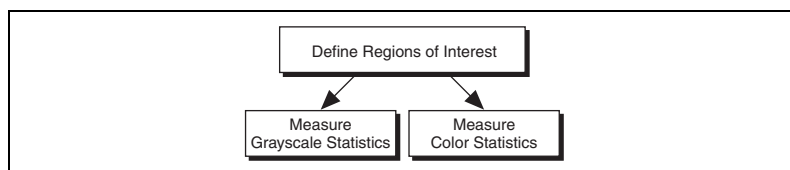


Figure 3-1. Steps to Taking Grayscale and Color Measurements

Define Regions of Interest

A region of interest (ROI) is an area of an image in which you want to focus your image analysis. You can define an ROI interactively, programmatically, or with an image mask.

Interactively Define Regions

You can interactively define an ROI in a window that displays an image. Use the tools from the IMAQ Vision tools palette to interactively define and manipulate an ROI. Table 3-1 describes each of the tools and the manner in which you use them.

Table 3-1. Tools Palette Functions














Icon	Tool Name	Function
	Selection Tool	Select an ROI in the image and adjust the position of its control points and contours. Action: Click on the desired ROI or control points.
	Point	Select a pixel in the image. Action: Click on the desired position.
	Line	Draw a line in the image. Action: Click on the initial position and click again on the final position.
	Rectangle	Draw a rectangle or square in the image. Action: Click on one corner and drag to the opposite corner.
	Rotated Rectangle	Draw a rotated rectangle in the image. Action: Click on one corner and drag to the opposite corner to create the rectangle. Then, click on the lines inside the rectangle and drag to adjust the rotation angle.
	Oval	Draw an oval or circle in the image. Action: Click on the center position and drag to the desired size.
	Annulus	Draw an annulus in the image. Action: Click on the center position and drag to the desired size. Adjust the inner and outer radii, and adjust the start and end angle.
	Broken Line	Draw a broken line in the image. Action: Click to place a new vertex and double-click to complete the ROI element.
	Polygon	Draw a polygon in the image. Action: Click to place a new vertex and double-click to complete the ROI element.
	Freehand Line	Draw a freehand line in the image. Action: Click on the initial position, drag to the desired shape and release the mouse button to complete the shape.

Table 3-1. Tools Palette Functions (Continued)

Icon	Tool Name	Function
	Freehand	Draw a freehand region in the image. Action: Click on the initial position, drag to the desired shape and release the mouse button to complete the shape.
	Zoom	Zoom-in or zoom-out in an image. Action: Click on the image.
	Pan	Pan around a zoomed-in image. Action: Click on an initial position, drag to the desired position and release the mouse button to complete the pan.

ROIs you draw in a window are context sensitive. Press the <Ctrl> key when drawing an ROI if you want to constrain the ROI to the horizontal or vertical axes or diagonal axes, when possible. Use the selection tool to position an ROI by its control points or vertices. If you want to draw more than one ROI in a window, press the <Shift> key while drawing additional ROIs.

You can display the IMAQ Vision tools palette as part of an ROI constructor window or in a separate, floating window. Follow these steps to invoke an ROI constructor and define an ROI from within the ROI constructor window:



1. Use the IMAQ ConstructROI VI (**Vision Utilities»Region of Interest**) to display an image and the tools palette in an ROI constructor window, as shown in Figure 3-2.

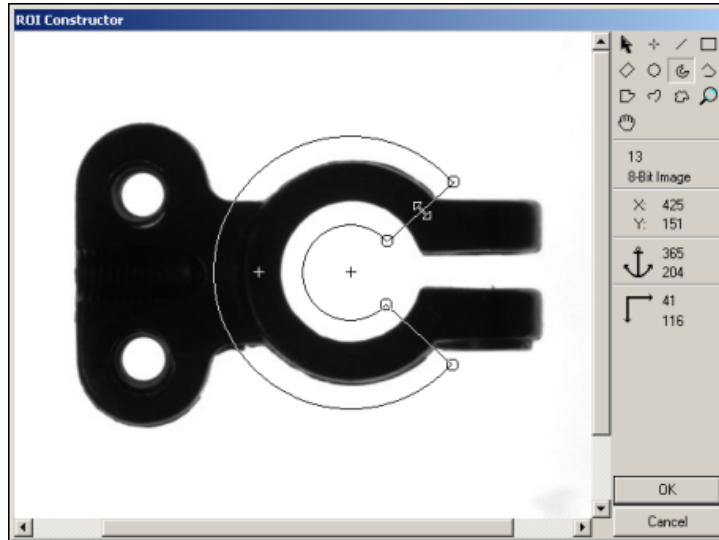


Figure 3-2. ROI Constructor

2. Select an ROI tool from the tools palette.
3. Draw an ROI on your image. Resize and reposition the ROI until it designates the area you want to inspect.
4. Click the OK button to output a descriptor of the region you selected. You can input the ROI descriptor into many analysis and processing functions. You can also convert the ROI descriptor into an image mask, which you can use to process selected regions in the image. Use the IMAQ ROItoMask VI (**Vision Utilities»Region of Interest**) to convert the ROI descriptor into an image mask.



The tools palette, shown in Figure 3-3, automatically transforms from the palette on the left to the palette on the right when you manipulate a region tool in an image window. The palette on the right displays the characteristics of the ROI you are drawing.

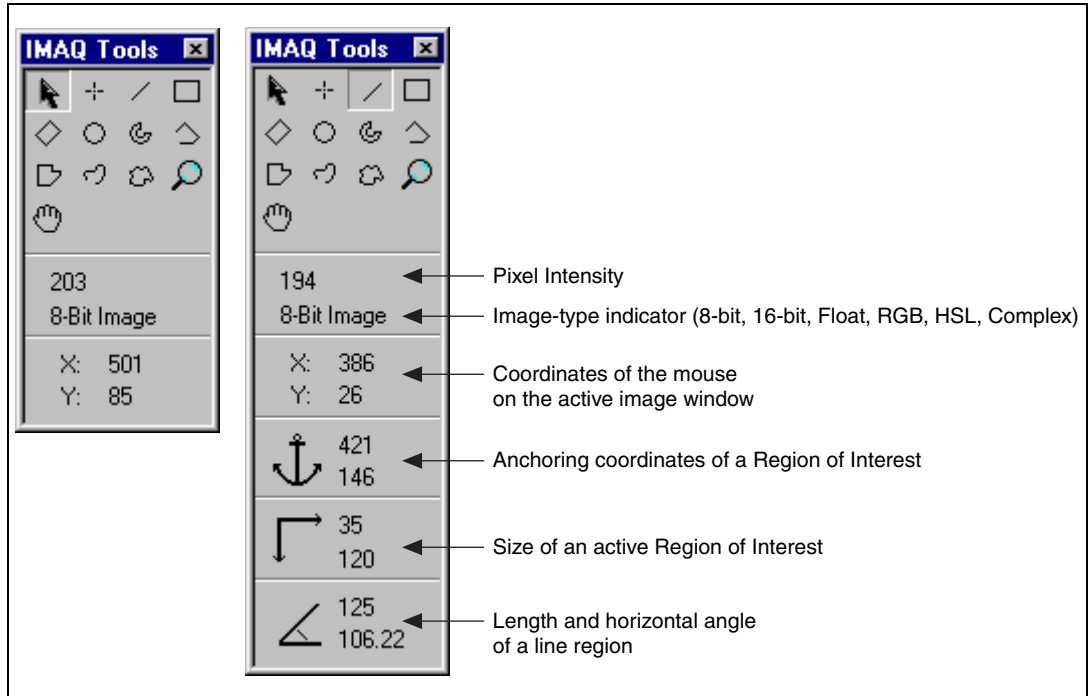


Figure 3-3. Tools Palette Tools and Information

The following list describes how you can display the tools palette in a separate window and manipulate the palette. You can find all the following VIs on the **Vision Utilities»Region of Interest** palette.



- Use the IMAQ WindToolsShow VI to display the tools window in a floating window.



- Use the IMAQ WindToolsSetup VI to configure the appearance of the tools window.



- Use the IMAQ WindToolsMove VI to move the tools palette.



- Use the IMAQ WindToolsClose VI to close the tools palette.



If you want to draw an ROI without using an ROI constructor or displaying the tools palette in a separate window, use the IMAQ WindToolsSelect VI (**Vision Utilities»Region of Interest**). This VI allows you to select a contour from the tools palette without opening the palette.



You can also use the IMAQ Select Point VI, IMAQ Select Line VI, and IMAQ Select Rectangle VI to define regions of interest. These three VIs appear in the **Machine Vision»Select Region of Interest** palette. Follow these steps to use these VIs:

1. Call the VI to display an image in an ROI Constructor window. Only the tools specific to that VI are available for you to use.
2. Draw an ROI on your image. Resize or reposition the ROI until it covers the area you want to process.
3. Click the OK button to output a simple description of the ROI. You can use this description as an input for the following VIs that measure grayscale intensity:
 - IMAQ Light Meter (Point)—Uses the output of IMAQ Select Point.
 - IMAQ Light Meter (Line)—Uses the output of IMAQ Select Line.
 - IMAQ Light Meter (Rect)—Uses the output of IMAQ Select Rectangle.

Programmatically Define Regions

When you have an automated application, you may need to define regions of interest programmatically. You can programmatically define regions in two ways:

- Specify the elements of an ROI descriptor, which are described below:
 - **Global rectangle**—Four integers that describe the bounding rectangle containing all of the shapes in the ROI descriptor.
 - **Contours**—Each of the individual shapes that define an ROI, as follows:
 - **ID**—Refers to whether the contour is the external or internal edge of an ROI. If the contour is external, all of the area inside of it is considered part of the ROI. Because external contours are calculated first, internal contours override external contours, giving you the ability to exclude regions inside external contours.
 - **Type**—The shape type of the contour.
 - **Coordinates**—An array containing the coordinates that define the contour.

Using ROI descriptors is an advanced procedure. For example VIs on how to programmatically create regions of interest, see the examples installed in LabVIEW\examples\Vision\2. Functions\Display.

- Specify regions by providing basic parameters that describe the region you want to define. For example, define a point by providing the x-coordinate and y-coordinate. Define a line by specifying the start and end coordinates. Define a rectangle by specifying the coordinates of the top, left point, and the bottom, right point, and the rotation angle.

The **Vision Utilities»Region of Interest»Region of Interest Conversion** palette provides VIs to convert simple data types—such as points, lines, rectangles, and annuluses—into an ROI descriptor. Use the following VIs to convert an ROI contour encoded by a simple description to an ROI descriptor for that contour:



- IMAQ Convert Point to ROI—Converts a point specified by its x and y coordinates



- IMAQ Convert Line to ROI—Converts a line specified by its start and end points



- IMAQ Convert Rectangle to ROI—Converts a rectangle specified by its top-left and bottom-right points and rotation angle



- IMAQ Convert Annulus to ROI—Converts an annulus specified by its center point, inner and outer radii and start and end angles



- IMAQ Convert Rectangle to ROI (Polygon)—Converts a rectangle specified by its top-left and bottom-right points and rotation angle to an ROI descriptor that uses a polygon to represent the rectangle

Use the following VIs to convert an ROI contour encoded by an ROI descriptor to a simple description for the contour.



- IMAQ Convert ROI to Point—The output point is specified by its x and y coordinates.



- IMAQ Convert ROI to Line—The output line is specified by its start and end points.



- IMAQ Convert ROI to Rectangle—The output rectangle is specified by its top-left point, bottom-right point, and rotation angle.



- IMAQ Convert ROI to Annulus—The output annulus is specified by its center point, inner and outer radii, and start and end angles.

Define Regions with Masks

You can define regions to process with image masks. An image mask is an 8-bit image of the same size as or smaller than the image you want to process. Pixels in the mask image determine whether the corresponding pixel in the image to process needs to be processed. If a pixel in the image mask has a value different than 0, the corresponding pixel in the image to process is processed. If a pixel in the image mask has a value of 0, the corresponding pixel in the image to process is left unchanged.

Use masks when you need to make intensity measurements on particles in an image. First, threshold your image to make a new binary image. For more information on binary images, see Chapter 4, *Blob Analysis*. You can input the binary image or a labelled version of the binary image as a mask image to the intensity measurement function. If you want to make color comparisons, convert the binary image into an ROI descriptor using the IMAQ MaskToROI VI (**Vision Utilities**»**Region of Interest**).



Measure Grayscale Statistics

You can measure grayscale statistics in images using light meters or quantitative analysis functions. You can obtain the center of energy for an image with the centroid function.



Use the IMAQ Light Meter (Point) VI (**Machine Vision**»**Measure Intensities**) to measure the light intensity at a point in the image. Use the IMAQ Light Meter (Line) VI (**Machine Vision**»**Measure Intensities**) to get the pixel value statistics along a line in the image: mean intensity, standard deviation, minimum intensity, and maximum intensity. Use the IMAQ Light Meter (Rectangle) VI (**Machine Vision**»**Measure Intensities**) to get the pixel value statistics within a rectangular region in an image.



Use the IMAQ Quantify VI (**Image Processing**»**Analysis**) to obtain the following statistics about the entire image or individual regions in the image: mean intensity, standard deviation, minimum intensity, maximum intensity, area, and the percentage of the image that you analyzed. You can specify regions in the image with a labeled image mask. A labeled image mask is a binary image that has been processed so that each region in the image mask has a unique intensity value. Use the IMAQ Label VI (**Image Processing**»**Processing**) to label your image mask.



Use the IMAQ Centroid VI (**Image Processing**»**Analysis**) to compute the energy center of the image, or of a region within an image.

Measure Color Statistics

Most image processing and analysis functions apply to 8-bit images. However, you can analyze and process individual components of a color image.



Using the IMAQ ExtractColorPlanes VI (**Vision Utilities»Color Utilities**), you can break down a color image into various sets of primary components, such as RGB (Red, Green, and Blue), HSI (Hue, Saturation, and Intensity), HSL (Hue, Saturation, and Luminance), or HSV (Hue, Saturation, and Value). Each component becomes an 8-bit image that you can process like any other grayscale image. Using the IMAQ ReplaceColorPlane VI (**Vision Utilities»Color Utilities**), you can reassemble a color image from a set of three 8-bit images, where each image becomes one of the three primary components. Figure 3-4 illustrates how a color image breaks down into its three components.

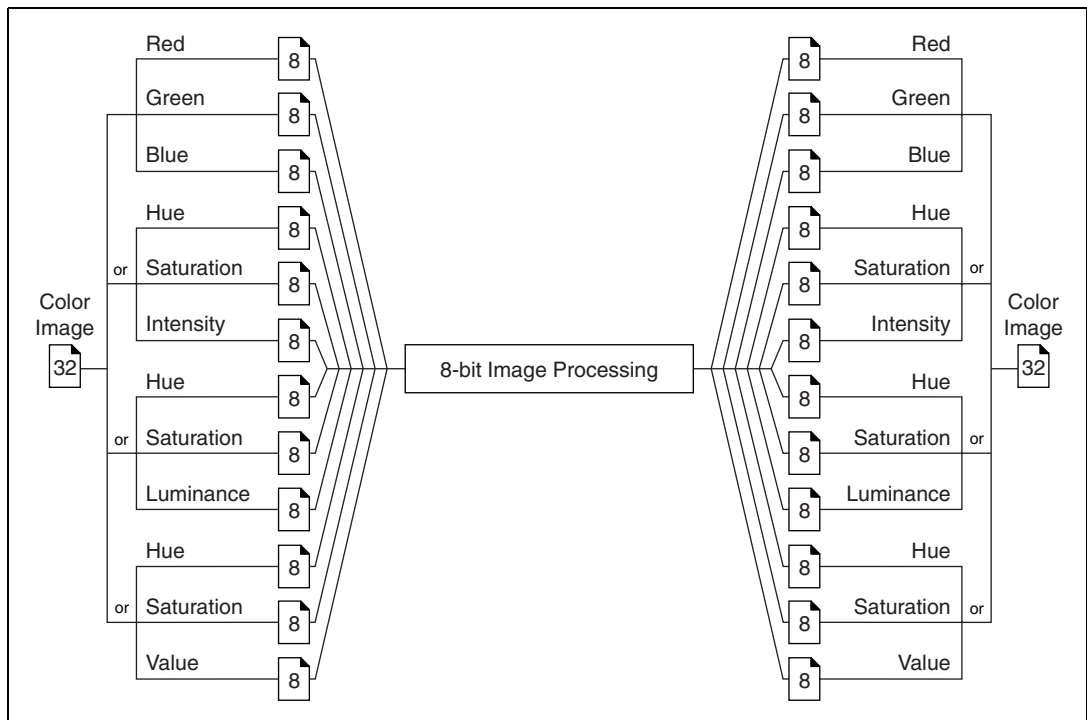


Figure 3-4. Primary Components of a Color Image



Use IMAQ ExtractSingleColorPlane or IMAQ ExtractColorPlanes (**Vision Utilities»Color Utilities**) to extract the red, green, blue, hue saturation, intensity, luminance, or value plane of a color image into an 8-bit image.



A color pixel encoded as an unsigned 32-bit integer control can be decomposed into its individual components using the IMAQ IntegerToColorValue VI. You can convert a pixel value represented by its RGB components into the equivalent components for another color model using the IMAQ RGBToColor VI. You can convert components in any other color mode to RGB by using the IMAQ ColorToRGB VI. These three VIs appear in the **Vision Utilities»Color Utilities** palette.

Color Comparison

You can use the color matching capability of IMAQ Vision to compare or evaluate the color content of an image or regions in an image.

Follow these steps to compare colors using color matching:

1. Select an image containing the color information that you want to use as a reference. The color information can be made up of multiple colors.
2. Use the entire image or regions in the image to learn the color information using the IMAQ ColorLearn VI (**Image Processing»Color Processing**), which outputs a color spectrum that contains a compact description of the color information that you learned. See Chapter 14, *Color Inspection*, of the *IMAQ Vision Concepts Manual* for more information. Use the color spectrum to represent the learned color information for all subsequent matching operations.
3. Define an image or multiple regions in an image as the inspection or comparison area.
4. Specify a Minimum Match Score, which indicates whether there is a match between the input color information and the color in each specified region in the image.
5. Use the IMAQ ColorMatch VI (**Image Processing»Color Processing**) to compare the learned color information to the color information in the inspection regions. This VI returns a score that indicates the closeness of match.
6. Use the color matching score as a measure of similarity between the reference color information and the color information in the image regions being compared.



Learning Color Information

When learning color information, you should choose the color information carefully by specifying an image or regions in an image that contain the color or color set that you want to learn, selecting how detailed you want the color information to be learned, and choosing colors that you want to ignore during matching.

Choosing the Right Color Information

Because color matching only uses color information to measure similarity, the image or regions in the image representing the object should contain only the significant colors that represent the object, as shown in Figure 3-5a. Figure 3-5b illustrates an unacceptable region containing background colors.

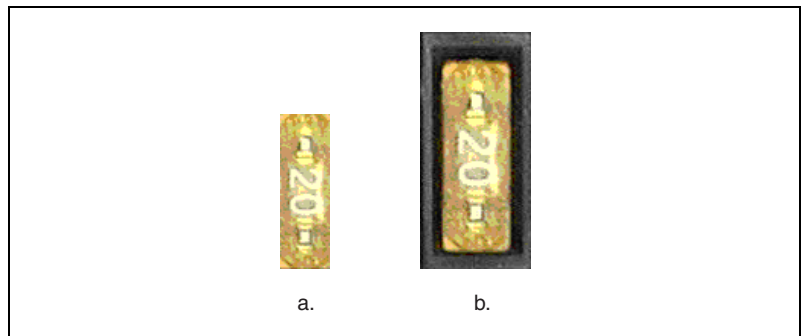


Figure 3-5. Template Color Information

Specifying the Color Information to Learn

You can learn the color information associated with an entire image, a region in an image, or multiple regions in an image.

Using the Entire Image

You can use an entire image to learn the color spectrum that represents the entire color distribution of the image. In a fabric identification application, for example, an entire image can specify the color information associated with a certain fabric type, as shown in Figure 3-6.

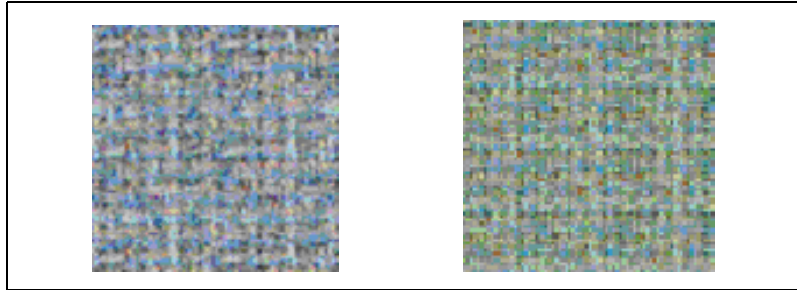


Figure 3-6. Using the Entire Image to Learn Color Distribution

Using a Region in the Image

You can select a region in the image to provide the color information for comparison. A region is helpful for pulling out the useful color information in an image. Figure 3-7 shows an example of using a region that contains the color information that is important for the application.



Figure 3-7. Using a Single Region to Learn Color Distribution

Using Multiple Regions in the Image

The interaction of light with an object's surface creates the observed color of that object. The color of a surface depends on the directions of illumination and the direction from which the surface is observed. Two identical objects may have different appearances because of a difference in positioning or a change in the lighting conditions. Figure 3-8 shows an example of how the reflection of the 3D surface of the fuse boxes is different for the fuses with the same kind resulting in slightly different colors (compare fuse marked "3" in the upper row and the similar one in the lower row). This results in different color spectrums for identical fuses.

If you learn the color spectrum by drawing a region of interest in the upper row fuse 3, and then do a color matching for the upper row fuse 3, you will get a very high match score for it (close to 1000). But the match score for

the lower row fuse 3 is quite low (around 500). This problem could cause a mismatch for the color matching in a fuse box inspection process.

IMAQ Vision's color learning software uses a clustering process to find the representative colors from the color information specified by one or multiple regions in the image. To create a representative color spectrum for fuse 3 in the learning phase, draw an ROI around fuse 3 in the upper row, hold down the <Shift> key, and draw another ROI around fuse 3 in the lower row. The new color spectrum represents fuse 3 much better and results in high match scores (around 800) for both the fuses. Use as many samples as you want in an image to learn the representative color spectrum for a specified template.

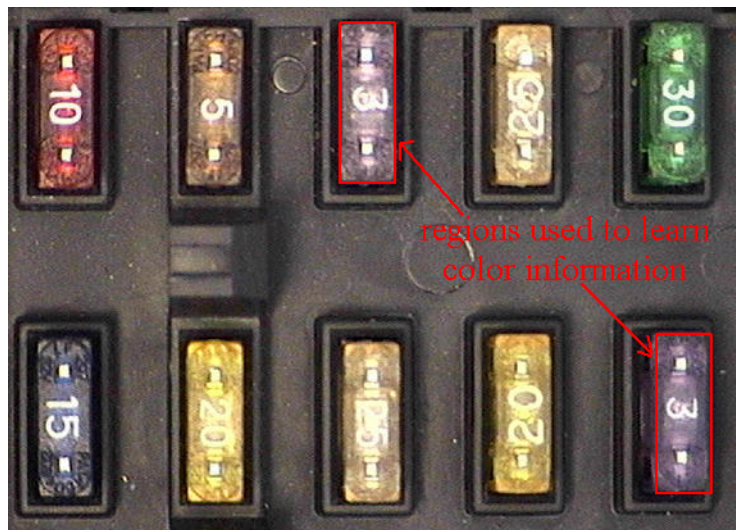


Figure 3-8. Using Multiple Regions to Learn Color Distribution

Choosing a Color Representation Sensitivity

When you learn a color, you need to specify the granularity required to specify the color information. An image containing a few, well-separated colors in the color space requires a lower granularity to describe the color than an image that contains colors that are close to one another in the color space. Use the color sensitivity parameter of the IMAQ ColorLearn VI to specify the granularity you want to use to represent the colors.

Ignoring Learned Colors

Ignore certain color components in color matching by replacing the corresponding component in the input color spectrum array to -1 . For example, by replacing the last component in the color spectrum with -1 , the white color is ignored during the color matching process. By replacing the second to last component in the color spectrum, the black color is ignored during the color matching process. To ignore other color components in color matching, determine the index to the color spectrum by locating the corresponding bins in the color wheel, where each bin corresponds to a component in the color spectrum array. Ignoring certain colors such as the background color results in a more accurate color matching score. Ignoring the background color also provides more flexibility when defining the regions of interest in the color matching process. Ignoring certain colors such as white color created by glare reflection, such as those from a metallic surface, also improves the accuracy of the color matching. Experiment learning the color information on different parts of the images to determine which colors to ignore. For more information about the color wheel and color bins, see Chapter 14, *Color Inspection*, in the *IMAQ Vision Concepts Manual*.

Blob Analysis

This chapter describes how to perform blob (Binary Large Object) analysis on your images. 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. Examples of how blob analysis can help you perform web inspection tasks include locating structural defects on wood planks or detecting cracks on plastic sheets.

Figure 4-1 illustrates the steps involved in performing blob analysis. Diagram items enclosed with dashed lines are optional steps.

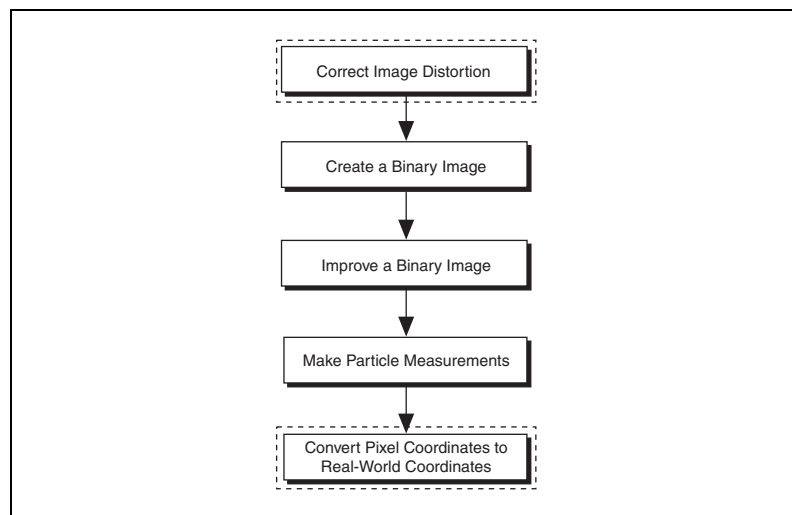


Figure 4-1. Steps to Performing Blob Analysis

Correct Image Distortion



If you need to make accurate shape measurements based on the blobs in an image containing perspective and nonlinear distortion errors, correct the distortion using the calibration information you attached to your image. Use the IMAQ Correct Calibrated Image VI (**Vision Utilities» Calibration**) to correct distortion in your grayscale image before thresholding it. See Chapter 6, *Calibration*, for more information about correcting an image using calibration information.

Create a Binary Image

Threshold your grayscale or color image to create a binary image. Creating a binary image separates the objects that you want to inspect from the background. The threshold operation sets the background pixels to 0 in the binary image, while setting the object pixels to a non-zero value. Object pixels have a value of 1 by default, but you can set the object pixels to have any value you choose.

You can use different techniques to threshold your image. If all the objects of interest in your grayscale image fall within a continuous range of intensities and you can specify this threshold range manually, use the IMAQ Threshold VI (**Image Processing»Processing**) to threshold your image. If all the objects in your grayscale image are either brighter or darker than your background, you can use one of the automatic thresholding techniques in IMAQ Vision. Follow these steps to use one of the automatic thresholding techniques:



1. Use the IMAQ AutoBThreshold VI (**Image Processing»Processing**) to select the thresholding technique that automatically determines the optimal threshold range.
2. Connect the **Threshold Data** output to the IMAQ MultiThreshold VI (**Image Processing»Processing**), or use the **Lookup Table** output to apply a lookup table to the image using the IMAQ UserLookup VI (**Image Processing»Processing**).

If your grayscale image contains objects that have multiple discontinuous grayscale values, use the IMAQ MultiThreshold VI (**Image Processing»Processing**).

Automatic thresholding techniques offer more flexibility than simple thresholds based on fixed ranges. Because automatic thresholding techniques determine the threshold level according to the image histogram,

the operation is more independent of changes in the overall brightness and contrast of the image than a fixed threshold. These techniques are more resistant to changes in lighting, which makes them well suited for automated inspection tasks.



If you need to threshold a color image, use the IMAQ ColorThreshold VI (**Image Processing»Color Processing**). You must specify threshold ranges for each of the color planes (either Red, Green, and Blue or Hue, Saturation, and Luminance). The binary image resulting from a color threshold is an 8-bit binary image.

Improve the Binary Image

After you threshold your image, you may want to improve the resulting binary image with binary morphological functions. You can use primary binary morphology or advanced binary morphology to remove unwanted blobs, separate connected blobs, or improve the shape of blobs. Primary morphology functions work on the image as a whole by processing pixels individually. Advanced morphology operations are built upon the primary morphological operators and work on particles as opposed to pixels.



Note The terms *blob* and *particle* are used interchangeably in this chapter.

The advanced morphology functions that improve binary images require that you specify the type of connectivity to use. Connectivity specifies how IMAQ Vision determines whether two adjacent pixels belong to the same particle. If you have a blob that contains narrow areas, use connectivity-8 to ensure that the software recognizes the pixels as one blob. If you have two blobs that touch at one point, use connectivity-4 to ensure that the software recognizes the pixels as two separate blobs. For more information about connectivity, see Chapter 9, *Binary Morphology*, of the *IMAQ Vision Concepts Manual*.



Note Use the same type of connectivity throughout your application.

Remove Unwanted Blobs



Use the IMAQ RejectBorder VI (**Image Processing»Morphology**) to remove blobs that touch the border of the image. Reject blobs on the border of the image when you suspect that the information about those blobs is incomplete.



Use the IMAQ RemoveParticle VI (**Image Processing»Morphology**) to remove large or small particles that do not interest you. You can also use the Erode, Open, and POpen functions in the IMAQ Morphology VI (**Image Processing»Morphology**) to remove small particles. Unlike the IMAQ RemoveParticle VI, these three functions alter the size and shape of the remaining blobs.

Use the hit-miss function of the IMAQ Morphology VI to locate particular configurations of pixels, which you define with a structuring element. Depending on the configuration of the structuring element, the hit-miss function can locate single isolated pixels, cross-shape or longitudinal patterns, right angles along the edges of particles, and other user-specified shapes. For more information about structuring elements, see Chapter 9, *Binary Morphology*, of the *IMAQ Vision Concepts Manual*.



If you know enough about the shape features of the blobs you want to keep, use the IMAQ ParticleFilter VI (**Image Processing»Morphology**) to filter out particles that do not interest you. If you do not have enough information about the particles you want to keep at this point in your processing, use the particle measurement VIs to obtain this information before applying a particle filter. See the [Make Particle Measurements](#) section for more information about the measurement VIs.

Separate Touching Blobs



Use the IMAQ Separation VI (**Image Processing»Morphology**) or apply an erosion or an open function with the IMAQ Morphology VI to separate touching objects. IMAQ Separation is an advanced VI that separates blobs without modifying their shapes. An erosion function alters the shape of the blobs.

Improve Blob Shapes



Use the IMAQ FillHoles VI (**Image Processing»Morphology**) to fill holes in the blobs. Use the IMAQ Morphology VI (**Image Processing»Morphology**) to perform a variety of operations on the blobs. You can use the Open, Close, POpen, PClose, and AutoM operations to smooth the boundaries of the blobs. Open and POpen smooth the boundaries of the blob by removing small isthmuses while Close widens the isthmuses. Close and PClose fill small holes in the blob. AutoM removes isthmuses and fills holes. For more information about these operations, see Chapter 9, *Binary Morphology*, in the *IMAQ Vision Concepts Manual*.

Make Particle Measurements

After you create a binary image and improve it, you can make particle measurements. With these measurements you can determine the location of blobs and their shape features. Use the following VIs to perform particle measurements:



- IMAQ BasicParticle (**Image Processing»Analysis**)—This VI returns the number of blobs in an image and a report containing the pixel area, real-world area, and bounding rectangle of the blobs. You can use the bounding rectangle to determine the location of the blob in the image.



- IMAQ ComplexParticle (**Image Processing»Analysis**)—This VI returns the number of blobs in an image and a report containing 16 of the most commonly used measurements, including the area, bounding rectangle, and perimeter of blobs.



- IMAQ ChooseMeasurements (**Image Processing»Analysis**)—This VI selects information about blobs from the reports generated by IMAQ BasicParticle or IMAQ ComplexParticle. Blobs that do not meet the criteria you set are filtered from the reports.



- IMAQ ComplexMeasure (**Image Processing»Analysis**)—This VI uses the reports from IMAQ ComplexParticle or IMAQ ChooseMeasurements to calculate 50 particle measurements.

Table 4-1 lists all of the measurements that the IMAQ ComplexMeasure VI returns.

Table 4-1. Particle Measurements

Measurement	Description
Area (pixels)	area of the particle in pixels
Area (calibrated)	area of the particle in user-defined units
Number of holes	number of holes within the particle
Holes area (pixels)	total area of the particle holes in pixels
Total area	area of the particle and its holes
Scanned area	area of the entire image in real-world units
Ratio area/Scanned area (%)	percentage of the surface area of a particle in relation to the scanned area

Table 4-1. Particle Measurements (Continued)

Measurement	Description
Ratio area / Total area (%)	percentage of a particle's surface area in relation to the total area
Center of mass (X)	x-coordinate of the center of mass
Center of mass (Y)	y-coordinate of the center of mass
Left column (X)	left x-coordinate of the bounding rectangle
Upper row (Y)	top y-coordinate of the bounding rectangle
Right column (X)	right x-coordinate of the bounding rectangle
Lower row (Y)	bottom y-coordinate of bounding rectangle
Width	width of bounding rectangle in user-defined units
Height	height of bounding rectangle in user-defined units
Longest segment length	length of longest horizontal line segment in a particle
Longest segment left column (X)	leftmost x-coordinate of longest horizontal line segment in a particle
Longest segment top row (Y)	y-coordinate of longest horizontal line segment
Perimeter	length of the outer contour of the particle in user-defined units
Hole's perimeter	perimeter of all holes in user-defined units
SumX	sum of the x-coordinates for each pixel of the particle
SumY	sum of the y-coordinates for each pixel of the particle

Table 4-1. Particle Measurements (Continued)

Measurement	Description
SumXX	sum of the squared x-coordinates for each pixel of the particle
SumYY	sum of the squared y-coordinates for each pixel of the particle
SumXY	sum of the product of the x-coordinate and y-coordinate for each pixel of the particle
Corrected projection X	sum of the horizontal segments that do not superimpose any other vertical segment
Corrected projection Y	sum of the vertical segments that do not superimpose any other horizontal segment
Moment of inertia Ixx	inertia matrix coefficient in XX
Moment of inertia Iyy	inertia matrix coefficient in YY
Moment of inertia Ixy	inertia matrix coefficient in XY
Mean chord X	mean length of horizontal segments
Mean chord Y	mean length of vertical segments
Max intercept	length of the longest segment in the convex hull of the particle
Mean intercept perpendicular	mean length of the chords in a particle perpendicular to its max intercept
Particle orientation	direction of the longest segment
Equivalent ellipse minor axis	total length of the axis of the ellipse having the same area as the particle and a major axis equal to half the max intercept
Ellipse major axis	total length of the major axis of the ellipse having the same area and perimeter as the particle in user-defined units

Table 4-1. Particle Measurements (Continued)

Measurement	Description
Ellipse minor axis	total length of the minor axis of the ellipse having the same area and perimeter as the particle in user-defined units
Ratio of equivalent ellipse axis	fraction of the length of the major axis to the length of the minor axis
Rectangle big side	length of the large side of a rectangle having the same area and perimeter as the particle in user-defined units
Rectangle small side	length of the small side of a rectangle having the same area and perimeter as the particle in user-defined units
Ratio of equivalent rectangle sides	ratio of rectangle big side to rectangle small side
Elongation factor	max intercept/mean perpendicular intercept
Compactness factor	particle area/(breadth × width)
Heywood circularity factor	particle perimeter/perimeter of circle having same area as the particle
Type factor	complex factor relating the surface area to the moment of inertia
Hydraulic radius	particle area/particle perimeter
Waddel disk diameter	diameter of the disk having the same area as the particle in user-defined units
Diagonal	diagonal of an equivalent rectangle in user-defined units

Convert Pixel Coordinates to Real-World Coordinates



The particle measurement functions return only the area of blobs in pixel coordinates. If you need to find the location of the center of mass or the bounding rectangle of the blobs in real-world units, use the IMAQ Convert Pixel to Real World VI (**Vision Utilities»Calibration**).

Machine Vision

This chapter describes how to perform many common machine vision inspection tasks. The most common inspection tasks are detecting the presence or absence of parts in an image and measuring 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 types of information.

Edge detectors and derivative techniques—such as rakes, concentric rakes, and spokes—use edges represented in the image. They locate with high accuracy the position of the edge of an object in the image. The edge location can then be used directly to measure for example the width of the part (clamps). Multiple edge locations can also be combined to compute intersection points, projections, circles or ellipse fits, and so on.

Algorithms of the Pattern Matching class use edges and patterns. Pattern Matching can locate with very high accuracy the position of fiducials or characteristic features of the part under inspection. Those locations can then be combined to compute lengths, angles, and other object measurements.

The robustness of your measurement directly relies on the stability of your image acquisition conditions. Sensor resolution, lighting, optics, vibration control, part fixture, and general environment are key components of the imaging setup. All the elements of the image acquisition chain directly affect the accuracy of the measurements.

Figure 5-1 illustrates the basic steps involved in performing machine vision. Diagram items enclosed with dashed lines are optional steps.

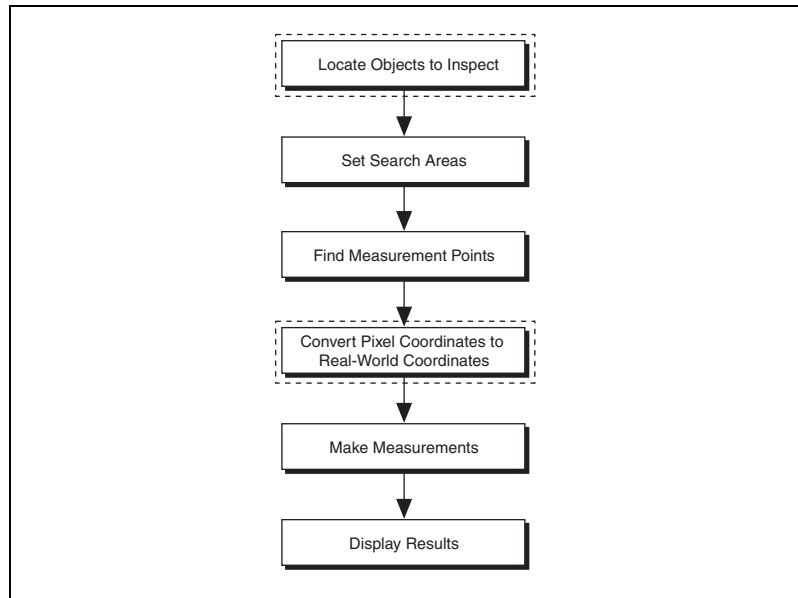


Figure 5-1. Steps to Performing Machine Vision

Locate Objects to Inspect

In a typical machine vision application, you extract measurements from regions of interest rather than the entire image. To use this technique, the parts of the object you are interested in must always appear inside the regions of interest you define.

If the object under inspection is always at the same location and orientation in the images you need to process, defining regions of interest is simple. See the [Set Search Areas](#) section for information about selecting a region of interest.

Often, the object under inspection appears shifted or rotated within the images you need to process. When this occurs, the regions of interest need to shift and rotate with the parts of the object you are interested in. In order for the regions of interest to move in relation to the object, you need to define a reference coordinate system relative to the object. After you define a reference coordinate system, the coordinate system moves in relation to the object, and the measurement VIs automatically move the regions of

interest to the correct position in the new coordinate system. For information about coordinate systems, see Chapter 13, *Dimensional Measurements*, of the *IMAQ Vision Concepts Manual*.

You can build a coordinate reference using edge detection or pattern matching. The output of the edge detection and pattern matching VIs that build a coordinate system are the origin, angle, and axes direction of the coordinate system. Some machine vision VIs take this output and adjust the regions of inspection automatically. You can also use these outputs to move the regions of inspection relative to the object programmatically.

Use Edge Detection to Build a Coordinate Reference



You can build a coordinate reference system using two edge detection techniques. Use the IMAQ Find CoordSys (Rect) VI (**Machine Vision» Coordinate Systems**) to define a coordinate system using one rectangular region. Use the IMAQ Find CoordSys (2 Rects) VI (**Machine Vision» Coordinate Systems**) to define a coordinate system using two independent rectangular regions. Follow the steps below to build a coordinate reference system using edge detection:



Note To use this technique, the object cannot rotate more than $\pm 65^\circ$ in the image.

1. Specify one or two rectangular regions.
 - a. If you use IMAQ Find CoordSys (Rect), specify one rectangular ROI that includes part of two straight, nonparallel boundaries of the object, as shown in Figure 5-2. This rectangular region must be large enough to include these boundaries in all the images you want to inspect.

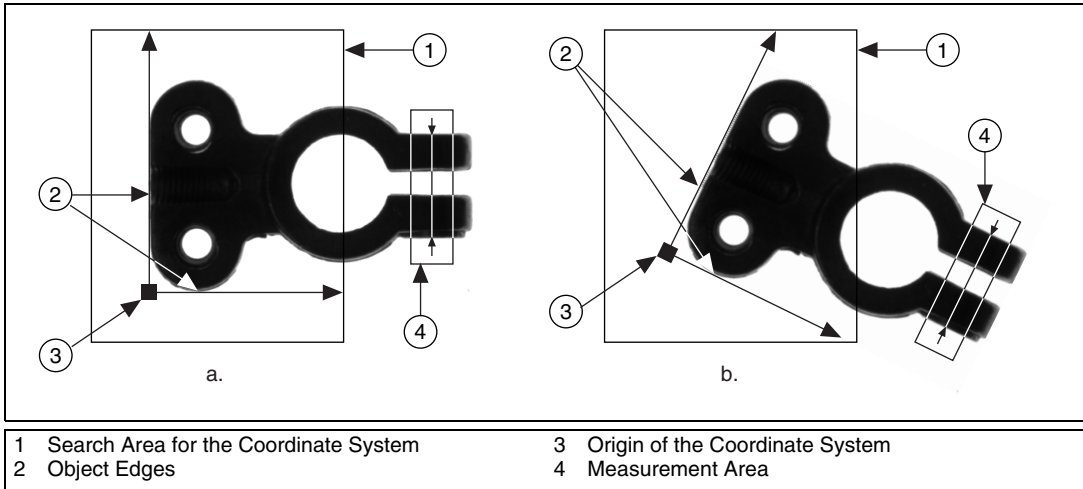


Figure 5-2. Coordinate Systems of a Reference Image and Inspection Image

- b. If you use IMAQ Find CoordSys (2 Rects), specify two rects, each containing one separate, straight boundary of the object, as shown in Figure 5-3. The boundaries cannot be parallel. The regions must be large enough to include the boundaries in all the images you want to inspect.

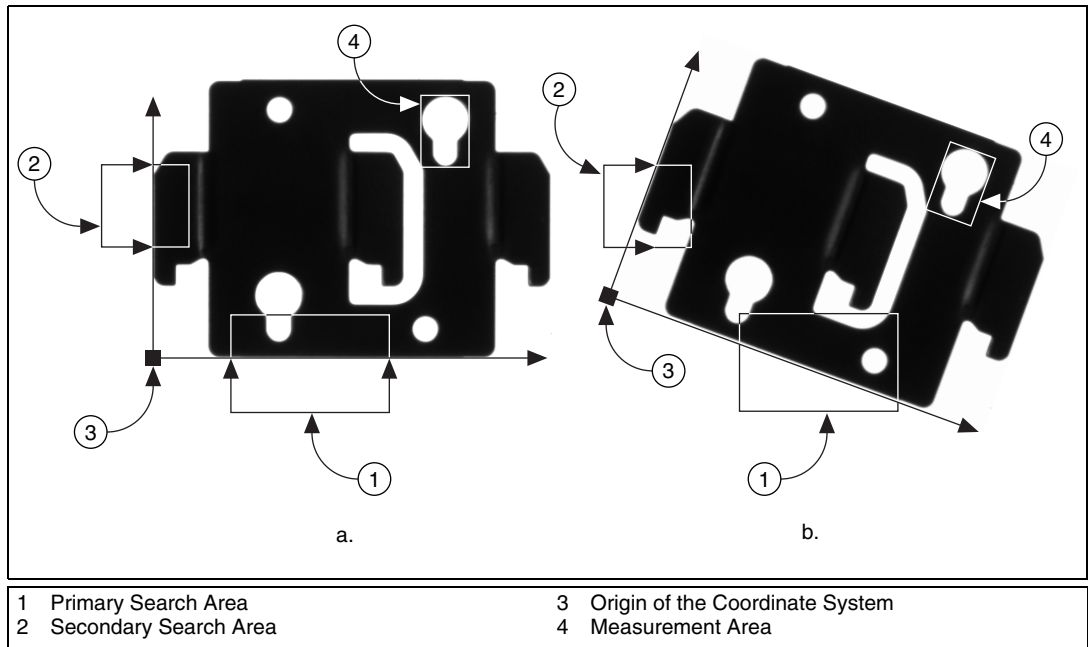


Figure 5-3. Locating Coordinate System Axes with Two Search Areas

2. Choose the parameters you need to locate the edges on the object.
3. Choose the coordinate system axis direction.
4. Choose the results that you want to overlay onto the image.
5. Choose the mode for the VI. To build a coordinate system for the first time, set mode to **Find Reference**. To update the coordinate system in subsequent images, set this mode to **Update Reference**.

Use Pattern Matching to Build a Coordinate Reference



You can build a coordinate reference system using pattern matching. Use the IMAQ Find CoordSys (Pattern) VI (**Machine Vision»Coordinate Systems**) to define a coordinate system based on the location of a reference feature. Use this technique when the object under inspection does not have straight, distinct edges. Follow the steps below to build a coordinate reference system using pattern matching:



Note The object may rotate more than $\pm 65^\circ$ in the image using this technique.

1. Define a template that represents the part of the object that you want to use as a reference feature. For more information about defining a template, see the *Find Measurement Points* section.
2. Define a rectangular search area in which you expect to find the template.
3. Choose the **Match Mode**. Select **Rotation Invariant** when you expect your template to appear rotated in the inspection images. Otherwise, select **Shift Invariant**.
4. Choose the results that you want to overlay onto the image.
5. Choose the mode for the VI. To build a coordinate system for the first time, set mode to **Find Reference**. To update the coordinate system in subsequent images, set this mode to **Update Reference**.

Choose a Method to Build the Coordinate System

The following flowchart guides you through choosing the best method for building a coordinate system for your application.

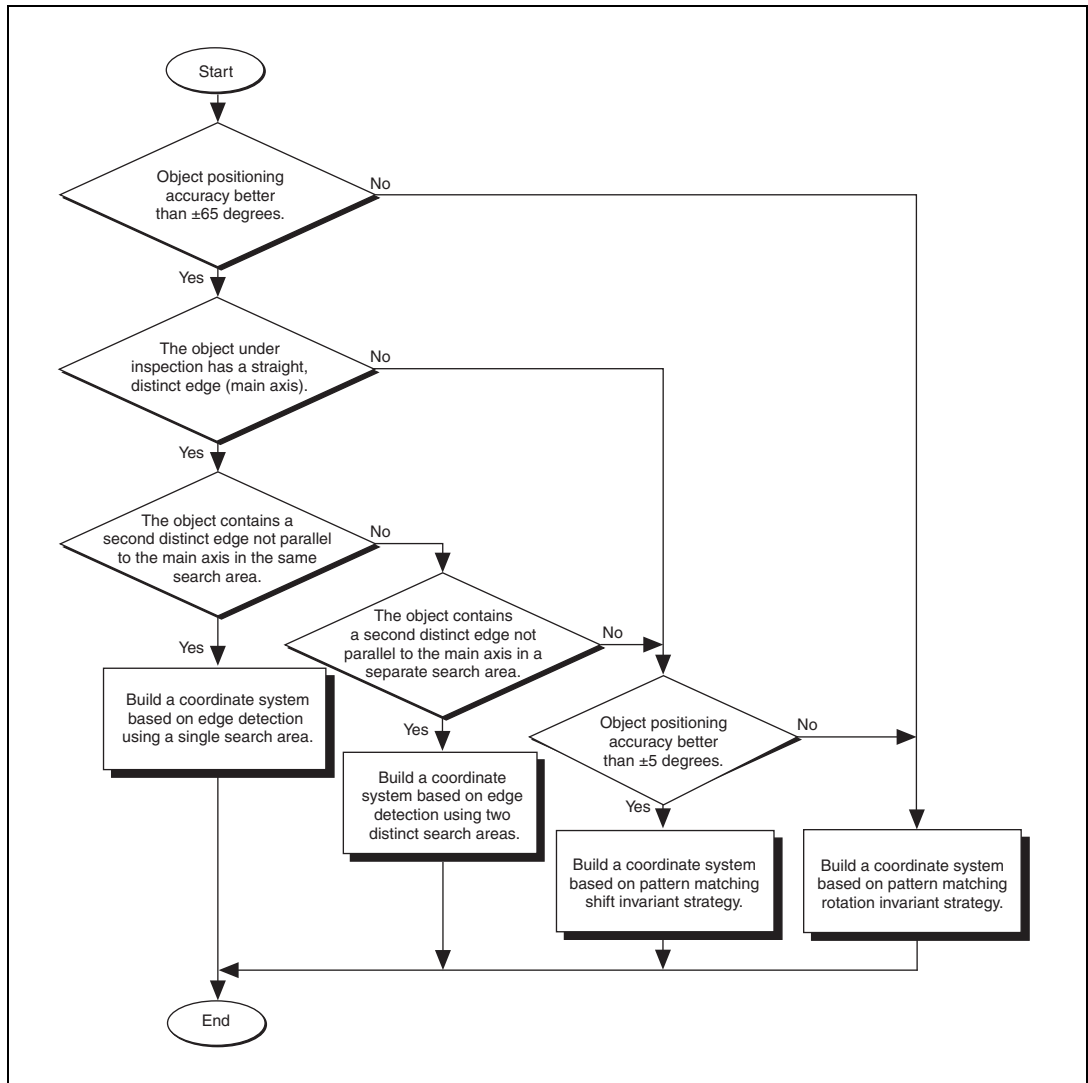


Figure 5-4. Building a Coordinate System

Set Search Areas

Select regions of interest (ROIs) in your images to limit the areas in which you perform your processing and inspection. You can define ROIs interactively or programmatically.

Interactively Define Regions



Follow these steps to interactively define an ROI:










1. Use the IMAQ ConstructROI VI (**Vision Utilities»Region of Interest**) to display an image and the tools palette in a window.
2. Select an ROI tool from the tools palette.
3. Draw an ROI on your image. Resize and reposition the ROI until it specifies the area you want to process.
4. Click the OK button to output a descriptor of the region you selected. You can input the ROI descriptor into many analysis and processing functions.



You can also use the IMAQ Select Rectangle VI (**Machine Vision»Select Region of Interest**) and the IMAQ Select Annulus VI (**Machine Vision»Select Region of Interest**) to define regions of interest. Follow these steps to use these VIs:

1. Call the VI to display an image in a window. Only the tools specific to that VI are available for you to use.
2. Select an ROI tool from the tools palette.
3. Draw an ROI on your image. Resize or reposition the ROI until it specifies the area you want to process.

Click the OK button to output a simple description of the ROI. You can use this description as an input for the following VIs:

ROI Selection VI	Measurement VI
	IMAQ Find Pattern (Machine Vision»Find Patterns)
	IMAQ Clamp Horizontal Max (Machine Vision»Measure Distances)
	IMAQ Clamp Horizontal Min (Machine Vision»Measure Distances)
	IMAQ Clamp Vertical Max (Machine Vision»Measure Distances)
	IMAQ Clamp Vertical Min (Machine Vision»Measure Distances)
	IMAQ Find Horizontal Edge (Machine Vision»Locate Edges)
	IMAQ Find Vertical Edge (Machine Vision»Locate Edges)
	IMAQ Find Circular Edge (Machine Vision»Locate Edges)
	IMAQ Find Concentric Edge (Machine Vision»Locate Edges)

Programmatically Define Regions

When you have an automated application, you need to define regions of interest programmatically. You can programmatically define regions in two ways:

- Specify the elements of the ROI descriptor.
- Specify regions by providing basic parameters that describe the region you want to define. You can specify a rectangle by providing the coordinates of the top, left point, and the bottom, right point, and the rotation angle. You can specify an annulus by providing the coordinates of the center, inner radius, outer radius, start angle, and end angle.

See Chapter 3, *Grayscale and Color Measurements*, for more information about defining regions of interest.

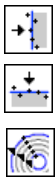
Find Measurement Points

After you set regions of inspection, locate points within those regions on which you can base measurements. You can locate measurement points using edge detection, pattern matching, color pattern matching, and color location.

Find Features Using Edge Detection

Use the edge detection tools to identify and locate sharp discontinuities in an image. Discontinuities typically represent abrupt changes in pixel intensity values, which characterize the boundaries of objects.

Find Lines or Circles



If you want to find points along the edge of an object and find a line describing the edge, use the IMAQ Find Vertical Edge, IMAQ Find Horizontal Edge, and IMAQ Find Concentric Edge VIs (**Machine Vision» Locate Edges**). IMAQ Find Vertical Edge and IMAQ Find Horizontal Edge find edges based on rectangular search areas, as shown in Figure 5-5. IMAQ Find Concentric Edge finds edges based on annular search areas.

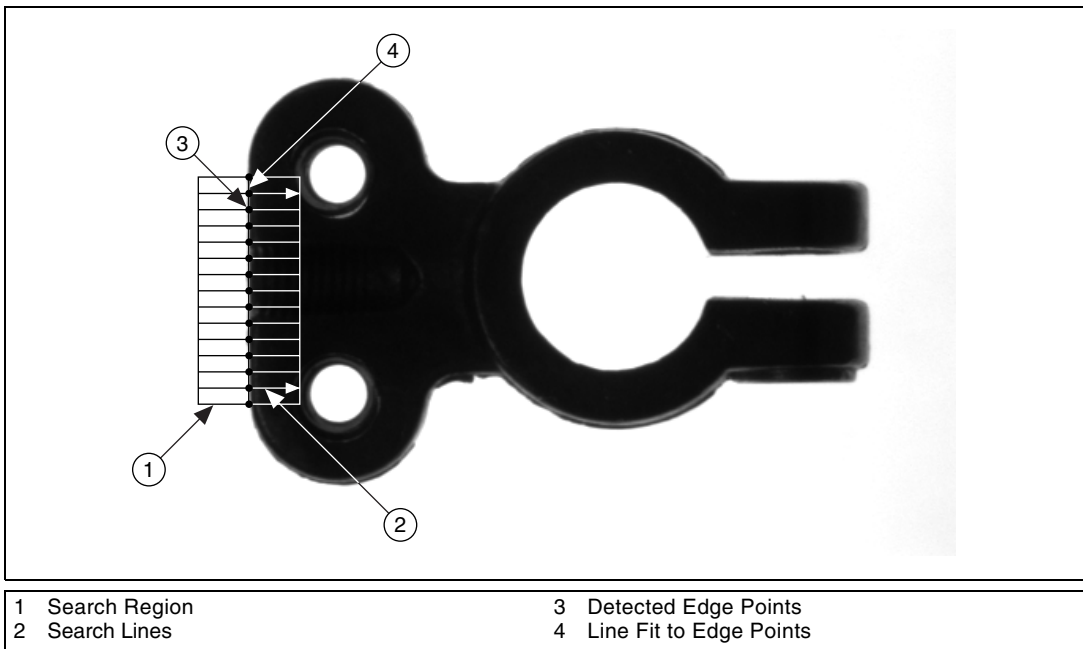


Figure 5-5. Finding a Straight Feature



If you want to find points along a circular edge and find the circle that best fits the edge, as shown in Figure 5-6, use the IMAQ Find Circular Edge VI (**Machine Vision»Locate Edges**).

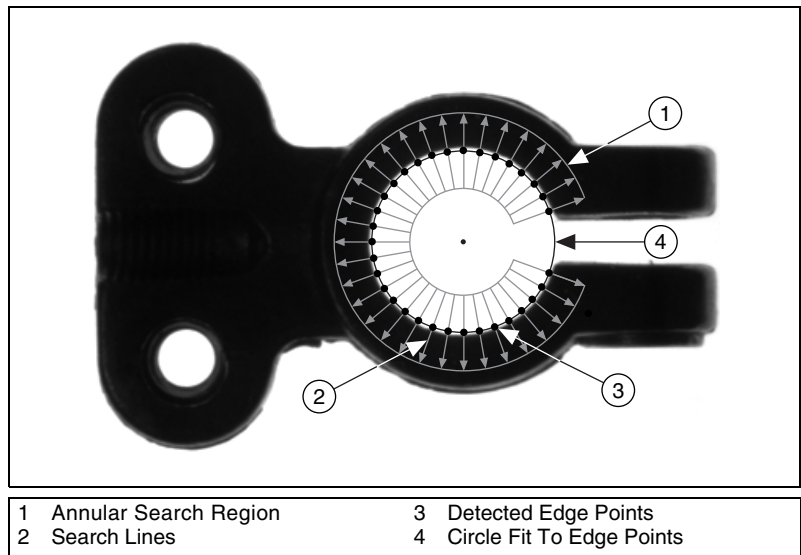


Figure 5-6. Finding a Circular Feature

These functions locate the intersection points between a set of search lines within the search region and the edge of an object. You can specify the search region using the IMAQ Select Rectangle VI (**Machine Vision»Select Region of Interest**) or the IMAQ Select Annulus VI (**Machine Vision»Select Region of Interest**). Specify the separation between the lines that the VI uses to detect edges. The VI determines the intersection points based on their contrast, width, and steepness. The software calculates a best-fit line with outliers rejection or a best-fit circle through the points it found. The VI returns the coordinates of the edge found.



Find Edge Points Along One Search Contour



Use the IMAQ Simple Edge VI (**Machine Vision»Caliper**) and the IMAQ Edge Tool VI (**Machine Vision»Caliper**) to find edge points along a contour. You can find the first edge, last edge, or all edges along the contour. Use IMAQ Simple Edge when your image contains little noise and the object and background are clearly differentiated. Otherwise, use IMAQ Edge Tool.



These VIs require you to input the coordinates of the points along the search contour. Use the IMAQ ROIProfile VI (**Image Processing»Analysis**) to obtain the coordinates from the ROI descriptor of the contour. If you have a straight line, use the IMAQ GetPointsOnLine VI (**Machine Vision»Analytic Geometry**) to obtain the points along the line instead of using an ROI descriptor.

These VIs determine the edge points based on their contrast and slope. You can specify whether you want to find the edge points using subpixel accuracy.

Find Edge Points Along Multiple Search Contours



Use the IMAQ Rake, IMAQ Spoke, and IMAQ Concentric Rake VIs (**Machine Vision»Caliper**) to find edge points along multiple search contours. These functions behave like the IMAQ Edge Tool VI behaves, but they find edges on multiple contours. Pass in an ROI descriptor to define the search region for these VIs.

IMAQ Rake works on a rectangular search region. The search lines are drawn parallel to the orientation of the rectangle. Control the number of search lines in the region by specifying the distance, in pixels, between each line. Specify the search direction as left to right or right to left for a horizontally oriented rectangle. Specify the search direction as top to bottom or bottom to top for a vertically oriented rectangle.

IMAQ Spoke works on an annular search region, scanning the search lines that are drawn from the center of the region to the outer boundary and that fall within the search area. Control the number of lines in the region by specifying the angle, in degrees, between each line. Specify the search direction as either going from the center outward or from the outer boundary to the center.

IMAQ Concentric Rake works on an annular search region. The concentric rake is an adaptation of the Rake to an annular region. Edge detection is performed along search lines that occur in the search region and that are concentric to the outer circular boundary. Control the number of concentric search lines that are used for the edge detection by specifying the radial distance between the concentric lines in pixels. Specify the direction of the search as either clockwise or counterclockwise.

Find Points Using Pattern Matching

The pattern matching tools in IMAQ Vision measure the similarity between an idealized representation of a feature, called a template, and the feature that may be present in an image. A feature is defined as a specific pattern of pixels in an image. Pattern matching returns the location of the center of the template and the template orientation. Follow these generalized steps to find features in an image using pattern matching:

1. Define a reference or fiducial pattern in the form of a template image.
2. Use the reference pattern to train the pattern matching tool.
3. Define an image or an area of an image as the search area. A small search area reduces the time to find the features.
4. Set the tolerances and parameters to specify how the tool operates at run time.
5. Test the search tool on test images.
6. Use a ranking method to verify results.

Define and Create Good Template Images

The selection of a good template image plays a critical part in obtaining good results. Because the template image represents the pattern that you want to find, make sure that all the important and unique characteristics of the pattern are well defined in the image. Several factors are critical in creating a template image, as follows:

- **Symmetry**—A rotationally symmetric template is less sensitive to changes in rotation than one that is rotationally asymmetric. A rotationally symmetric template provides good positioning information but no orientation information.

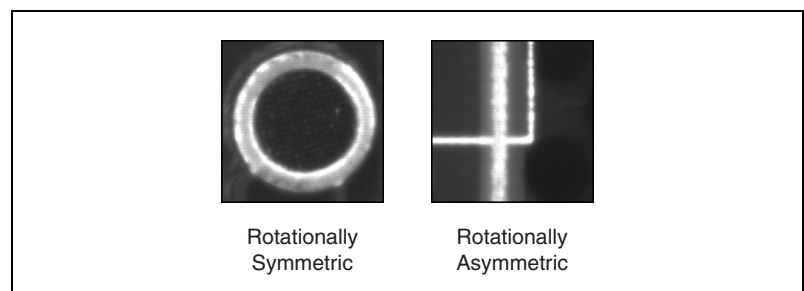


Figure 5-7. Symmetry

- **Feature detail**—A template with relatively coarse features is less sensitive to variations in size and rotation than a model with fine features. However, the model must contain enough detail to identify it.

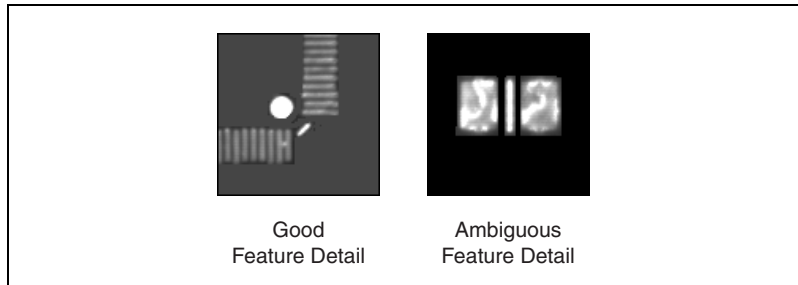


Figure 5-8. Feature Detail

- **Positional information**—A template with strong edges in both the x and y directions is easier to locate.

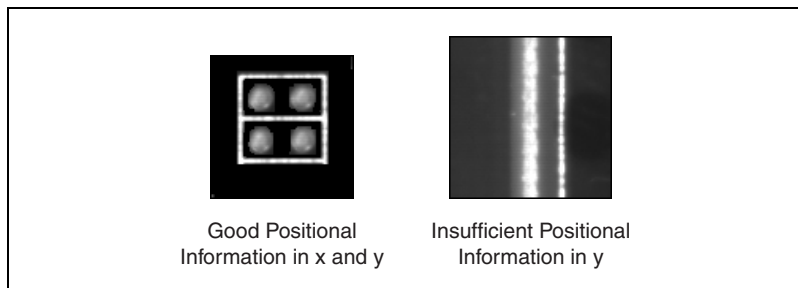


Figure 5-9. Positional Information

- **Background information**—Unique background information in a template improves search performance and accuracy.

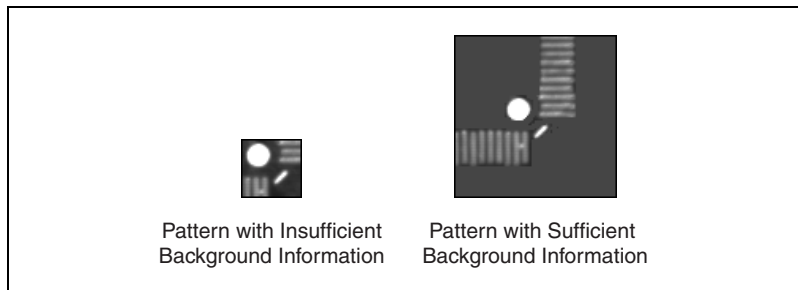


Figure 5-10. Background Information

Learn the Template

After you create a good template image, the pattern matching tool has to learn the important features of the template. The learning process depends on the type of matching that you expect to perform. If you do not expect the instance of the template in the image to rotate or change its size, then the pattern matching tool has to learn only those features from the template that are necessary for shift-invariant matching. However, if you want to match the template at any orientation, the learning process must consider the possibility of arbitrary orientations. Use the IMAQ Setup Learn Pattern VI (**Machine Vision»Searching and Matching**) to specify which type of learning mode to use.



After you run IMAQ Setup Learn Pattern, use the IMAQ Learn Pattern VI (**Machine Vision»Searching and Matching**) to learn the template. The learning process is usually time intensive because the algorithm attempts to find the optimum features of the template for the particular matching process. You can train the pattern matching tool offline and then save the template image by using the IMAQ Write Image and Vision Info VI (**Machine Vision»Searching and Matching**).

Define a Search Area

Two equally important factors define the success of a pattern matching tool: accuracy and speed. You can define a search area to reduce ambiguity in the search process. For example, if your image has multiple instances of a pattern and only one of them is required for the inspection task, the presence of additional instances of the pattern can produce incorrect results. To avoid this, reduce the search area so that only the desired pattern lies within the search area.

The time required to locate a pattern in an image depends on both the template size and the search area. As the size of the search area increases, the search time also increases. By reducing the search area, you can reduce the required search time.

In many inspection applications, you have general information about the location of the fiducial. You should use this information to define a search area. For example, in a typical component placement application, each printed circuit board (pcb) being tested may not be placed in the same location with the same orientation. The location of the pcb in various images can move and rotate within a known range of values, as illustrated in Figure 5-11. Figure 5-11a shows the template used to locate the pcb in the image. Figure 5-11b shows an image containing a pcb with a fiducial you want to locate. Notice the search area around the fiducial. If you know

before the matching process begins that the pcb can shift or rotate in the image within a fixed range (as shown in Figure 5-11c and Figure 5-11d, respectively), then you can limit the search for the fiducial to a small region of the image.

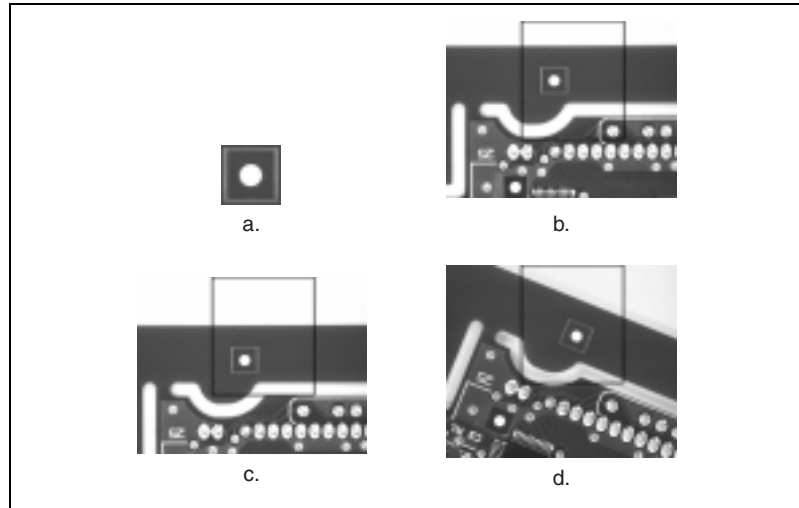


Figure 5-11. Selecting a Search Area for Grayscale Pattern Matching

Set Matching Parameters and Tolerances

Every pattern matching algorithm makes assumptions about the images and pattern matching parameters used in machine vision applications. These assumptions work for a high percentage of the applications. However, there may be applications in which the default values of the parameters used in the algorithm are not optimal. Knowing your particular application and the images you want to process is useful in selecting the pattern matching parameters. Use the IMAQ Setup Match Pattern VI (**Machine Vision»Searching and Matching**) to set the following two parameters:



- Minimum Contrast**—You can use the minimum contrast parameter to potentially increase the pattern matching tool's speed. Contrast is the difference between the smallest and largest pixel values in a region. The pattern matching tool ignores all image regions where contrast values fall beneath a set minimum contrast value. If the search image has high contrast but contains some low contrast regions, you can set a high minimum contrast value. By using a high minimum contrast value, you exclude all areas in the image with low contrast, significantly reducing the region in which the pattern matching tool

must search. If the search image has low contrast throughout, set a low minimum contrast parameter to ensure that the pattern matching tool looks for the template in all regions of the image.

- **Rotation Angle Ranges**—For matching objects that may rotate in the image, the pattern matching algorithm, by default, allows any orientation between 0° to 360° . If the pattern rotation in your application is restricted to a certain range (for example, from -15° to 15°), you can provide this information to the pattern matching algorithm by setting the Rotation Angle Ranges parameter. This information improves your search time because the pattern matching tool looks for the pattern at fewer angles.

Test the Search Tool on Test Images



To determine if your selected template or reference pattern is appropriate for your machine vision application, test the template on a few test images by using the IMAQ Match Pattern VI (**Machine Vision»Searching and Matching**). These test images should reflect the images generated by your machine vision application during true operating conditions. If the pattern matching tool locates the reference pattern in all cases, you have selected a good template. Otherwise, refine the current template, or select a better template until both training and testing are successful.

Use a Ranking Method to Verify Results

The manner in which you interpret the pattern matching tool depends on your application. For typical alignment applications, such as finding a fiducial on a wafer, the most important information is the position and location of the best match.

In inspection applications, such as optical character verification (OCV), the score of the best match is more useful. The score of a match returned by the pattern matching tool is an indicator of the closeness between the original pattern and the match found in the image. A high score indicates a very close match, while a low score indicates a poor match. The score can be used as a gauge to determine whether a printed character is acceptable.

Find Points Using Color Pattern Matching

Color pattern matching algorithms provide a quick way to locate objects when color is present. Use color pattern matching if:

- The object you want to locate has color information that is very different from the background, and you want to find a very precise location of the object in the image.
- The object 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 can give inaccurate results. If the object has 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.

Color pattern matching returns the location of the center of the template and the template orientation. Follow these general steps to find features in an image using color pattern matching:

1. Define a reference or fiducial pattern in the form of a template image.
2. Use the reference pattern to train the color pattern matching tool.
3. Define an image or an area of an image as the search area. A small search area reduces the time to find the pattern.
4. Set the tolerances and parameters to specify how the tool operates at run time.
5. Test the search tool on test images.
6. Use a ranking method to verify results.

Defining and Creating Good Color Template Images

The selection of a good template image plays a critical part in obtaining accurate results with the color pattern matching tool. Because the template image represents the color and the pattern that you want to find, make sure that all the important and unique characteristics of the pattern are well defined in the image.

Several factors are critical in creating a template image. These critical factors include color information, symmetry, feature detail, positional information, and background explanation.

Color Information

A template with colors that are unique to the pattern provides better results than a template that contains many colors, especially colors found in the background or other objects in the image.

Symmetry

A rotationally symmetric template in the luminance plane is less sensitive to changes in rotation than one that is rotationally asymmetric.

Feature Detail

A template with relatively coarse features is less sensitive to variations in size and rotation than a model with fine features. However, the model must contain enough detail to identify it.

Positional Information

A template with strong edges in both the x and y directions is easier to locate.

Background Information

Unique background information in a template improves search performance and accuracy during the grayscale pattern matching phase. This requirement could conflict with the “color information” requirement because background colors may not be desirable during the color location phase. Avoid this problem by choosing a template with sufficient background information for grayscale pattern matching while specifying the exclusion of the background color during the color location phase. Refer to the [Setting Matching Parameters and Tolerances](#) section for more information on how to ignore colors.

Using the Reference Pattern to Train the Color Pattern Matching Tool

After you have created a good template image, the color pattern matching tool learns the important features of the template. The learning process depends on the type of matching that you expect to perform. By default, the color pattern matching tool learns only those features from the template that are necessary for shift-invariant matching. However, if you want to match the template at any orientation, the learning process must consider the possibility of arbitrary orientations.



Note Use the IMAQ Setup Learn Color Pattern VI (**Machine Vision»Searching and Matching**) to specify which type of learning mode to use. Then use the IMAQ Learn Color Pattern VI (**Machine Vision»Searching and Matching**) to learn the template.



The training or learning process is time-intensive because the algorithm attempts to find optimal features of the template for the particular matching process. However, you can train the pattern matching tool offline, and save the template image using the IMAQ Write Image and Vision Info VI (**Machine Vision»Searching and Matching**).

Defining a Search Area

Two equally important factors define the success of a color pattern matching tool—accuracy and speed. You can define a search area to reduce ambiguity in the search process. For example, if your image has multiple instances of a pattern and only one instance is required for the inspection task, the presence of additional instances of the pattern can produce incorrect results. To avoid this, reduce the search area so that only the desired pattern lies within the search area. For example, in the fuse box inspection example use the location of the fuses to be inspected to define the search area. Because the inspected fuse box may not be in the exact location or have the same orientation in the image as the previous one, the search area you define should be large enough to accommodate these variations in the position of the box. Figure 5-12 shows how search areas can be selected for different objects.

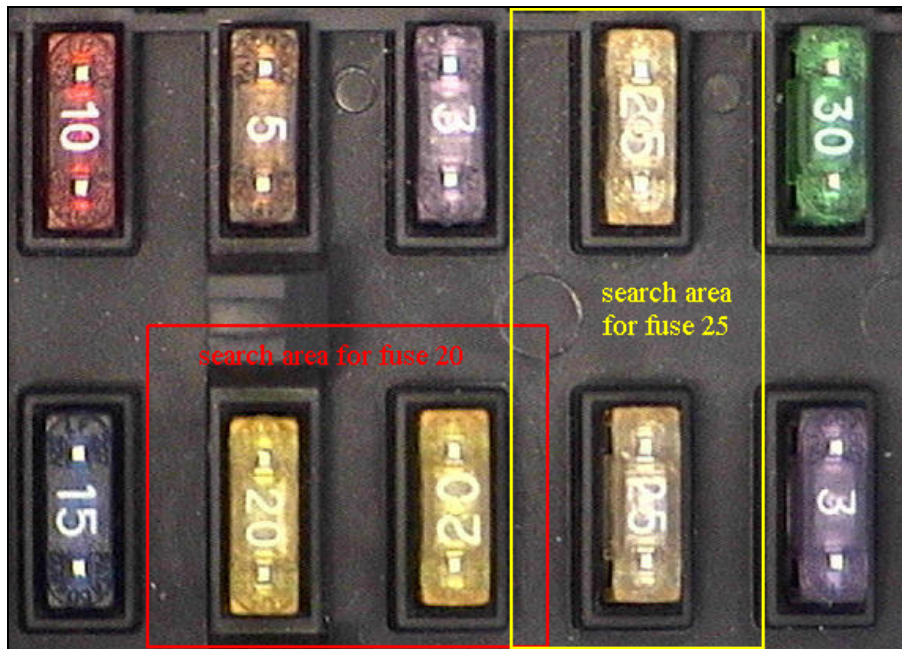


Figure 5-12. Selecting a Search Area for Color Pattern Matching

The time required to locate a pattern in an image depends on both the template size and the search area. As the size of the search area increases, the search time also increases. Reducing the search area reduces the required search time.

Setting Matching Parameters and Tolerances

Every color pattern matching algorithm makes assumptions about the images and color pattern matching parameters used in machine vision applications. These assumptions work for a high percentage of the applications.

In some applications, the default values of the parameters used in the algorithm are not optimal. In such cases the you must modify color pattern matching parameters. Knowing your particular application and the images you want to process is useful in selecting the pattern matching parameters. Use the IMAQ Setup Match Color Pattern VI (**Machine Vision»Searching and Matching**) to set this parameter.



The following are some parameters in the IMAQ Vision pattern matching tool and how they influence pattern matching: color sensitivity, search strategy, ignore background colors, minimum contrast, and rotation angle ranges.

Color Sensitivity

Use the color sensitivity parameter to control the granularity of the color information in the template image. If the background and objects in the image contain colors that are very close to colors in the template image, use a higher color sensitivity setting. A higher sensitivity setting distinguishes colors with very close hue values. Three color sensitivity settings are available in IMAQ Vision: Low, Medium and High. Use the default Low setting if the colors in the template are very different from the colors in the background or other objects that you are not interested in. Increase the color sensitivity settings as the color differences decrease. For more information on color sensitivity, see Chapter 14, *Color Inspection*, of the *IMAQ Vision Concepts Manual*.

Search Strategy

Use the search strategy parameter to optimize the speed of the color pattern matching tool. The search strategy controls the step size, sub-sampling factor, percentage of color information used from the template.

Choose from three different strategies:

- **Aggressive**—Uses the largest step size, the most sub-sampling and only the dominant color from the template to search for the template. Use this strategy when the color in the template is almost uniform, the template is well contrasted from the background and there is a good amount of separation between different occurrences of the template in the image. The Aggressive strategy is the fastest way to find templates in an image.
- **Conservative**—Uses a very small step size, a sub-sampling factor of two, and all the color information present in the template. The Conservative strategy is the most reliable method to look for a template in any image at potentially reduced speed.



Note Use the Conservative strategy if you have multiple targets located very close to each other in the image.

- **Balanced**—Uses values in between the Aggressive and Conservative strategies.

Decide on the best strategy by experimenting with the different options.

Color Score Weight

When you search for a template using both color and shape information, the color and shape scores generated during the match process are combined using the color score weight. The color score weight determines the contribution of the color score to the final color pattern matching score. The software uses the color score weight for the final match ranking. If the template's color information is superior to its shape information, set the weight higher. For example, if you use a weight of 1000, the algorithm finds each match by using both color and shape information and then ranks the matches based on their color scores. If the weight is 0, the matches are ranked based on their shape scores.

Ignore Background Colors

Use the ignore background colors parameter to exclude colors in the template that you are not interested in using during the search phase. Typically this parameter is used to ignore colors that either belong to the background of the object or are not unique to the template. This option reduces the potential for wrong matches during the color location phase.

Minimum Contrast

Use the minimum contrast parameter to increase the color pattern matching tool's speed. The color pattern matching tool ignores all image regions where grayscale contrast values fall beneath a set minimum contrast value. See the *Set Matching Parameters and Tolerances* section of this chapter for more information about minimum contrast. See Chapter 12, *Pattern Matching*, in the *IMAQ Vision Concepts Manual* for more information on pattern matching.

Rotation Angle Ranges

If you know that the pattern rotation is restricted to a certain range (for example, between -15° to 15°), provide this restriction information to the pattern matching algorithm by setting the **Rotation Angle Ranges** parameter. This information improves your search time because the color pattern matching tool looks for the pattern at fewer angles. See Chapter 12, *Pattern Matching*, in the *IMAQ Vision Concepts Manual* for more information on pattern matching.

Test the Search Tool on Test Images

To determine if your selected template or reference pattern is appropriate for your machine vision application, test the template on a few test images. For more information about testing the reference pattern, see the *Test the Search Tool on Test Images* section under *Find Points Using Pattern Matching*.

Find Points Using Color Location

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 the color arrangement in the region

- Does not require the orientation of the region
- Does not always require the location with sub-pixel accuracy
- Does not require shape information for the region

Follow these general steps to find features in an image using color location:

1. Define a reference pattern in the form of a template image.
2. Use the reference pattern to train the color location tool.
3. Define an image or an area of an image as the search area. A small search area reduces the time to find the features.
4. Set the tolerances and parameters to specify how the tool operates at run time.
5. Test the color location tool on test images.



You can save the template image using the IMAQ Write Image and Vision Info VI (**Machine Vision»Searching and Matching**).

Convert Pixel Coordinates to Real-World Coordinates



The measurement points you located with edge detection and pattern matching are in pixel coordinates. If you need to make measurements using real-world units, use the IMAQ Convert Pixel to Real World VI (**Vision Utilities»Calibration**) to convert the pixel coordinates into real-world units.

Make Measurements

You can make different types of measurements either directly from the image or from points that you detect in the image.

Distance Measurements

Use the following VIs to make distance measurements for your inspection application.

Clamp functions measure the separation between two edges in a rectangular search region. First, clamp VIs detect points along the two edges using the rake function. Then, they compute the distance between the points detected on the edges along each search line of the rake and return the largest or smallest distance. The IMAQ Select Rectangle VI (**Machine Vision»Select Region of Interest**) generates a valid input search region for these VIs. You also need to specify the parameters for edge detection and



the separation between the search lines that you want to use within search region to find the edges. These VIs work directly on the image under inspection, and they output the coordinates of all the edge points that they find. The following list describes the available clamp VIs:



- IMAQ Clamp Horizontal Max (**Machine Vision»Measure Distances**)—Measures the largest horizontal separation between two edges in a rectangular search region.



- IMAQ Clamp Horizontal Min (**Machine Vision»Measure Distances**)—Finds the smallest horizontal separation between two vertically oriented edges.



- IMAQ Clamp Vertical Max (**Machine Vision»Measure Distances**)—Finds the largest vertical separation between two horizontally oriented edges.



- IMAQ Clamp Vertical Min (**Machine Vision»Measure Distances**)—Finds the smallest vertical separation between two horizontally oriented edges.



Use the IMAQ Point Distances VI (**Machine Vision»Analytic Geometry**) to compute the distances between consecutive pairs of points in an array of points. You can obtain these points from the image using any one of the feature detection methods described in the [Find Measurement Points](#) section of this chapter.

Analytic Geometry Measurements

Use the following VIs (**Machine Vision»Analytic Geometry**) to make geometrical measurements from the points you detect in the image:



- IMAQ Fit Line—Fits a line to a set of points and computes the equation of the line.



- IMAQ Fit Circle—Fits a circle to a set of points and computes its area, perimeter and radius.



- IMAQ Fit Ellipse—Fits an ellipse to a set of points and computes its area, perimeter, and the lengths of its major and minor axis.



- IMAQ Lines Intersection—Finds the intersection point of two lines specified by their start and end points.



- IMAQ Perpendicular Line—Finds the perpendicular line from a point to line computes the perpendicular distance between the point and the line.



- IMAQ Bisecting Line—Finds the line that bisects the angle formed by two lines.



- IMAQ Mid Line—Finds the line that is midway between a point and a line and is parallel to the line.



- IMAQ Polygon Area—Calculates the area of a polygon specified by its vertex points.

Instrument Reader Measurements

You can make measurements based on the values obtained by meter, LCD, and barcode readers.



Use the IMAQ Get Meter or IMAQ Get Meter 2 VIs (**Machine Vision»Instrument Readers**) to calibrate a meter or gauge that you want to read.



IMAQ Get Meter calibrates the meter using the initial position and the full-scale position of the needle. This VI calculates the position of the base of the needle and the arc traced by the tip of the needle. IMAQ Get Meter 2 calibrates the meter using three points on the meter: the base of the needle, the tip of the needle at its initial position, and the tip of the needle at its full-scale position. This VI calculates the position of the points along the arc covered by the tip of the needle. Use the IMAQ Read Meter VI (**Machine Vision»Instrument Readers**) to read the position of the needle using the base of the needle and the array of points on the arc traced by the tip of the needle.



Use the IMAQ Get LCD ROI VI (**Machine Vision»Instrument Readers**) to calculate the regions of interest around each digit in an LCD or LED.



To find the area of each digit, all the segments of the indicator must be activated. Use the IMAQ Read Single Digit VI (**Machine Vision»Instrument Readers**) to read one digit of an LCD or LED.



Use the IMAQ Read LCD VI (**Machine Vision»Instrument Readers**) to read multiple digits of an LCD or LED.



Use the IMAQ Read Barcode VI (**Machine Vision»Instrument Readers**) to read values encoded in 1D barcodes. First, specify a region of interest that encloses the barcode information, and specify the type of barcode. Then, read the barcode.

Display Results

You can display the results obtained at various stages of your inspection process on the window that displays your inspection image. You can do this by overlaying information on an image. The software attaches the information that you want to overlay to the image, but it does not modify the image. The overlay appears every time you display the image in an external window.

Use the following VIs (**Vision Utilities»Overlay**) to overlay search regions, inspection results, and other information, such as text and bitmaps.



- IMAQ Overlay Points—Overlays points on an image. Specify a point by its x-coordinate and y-coordinate.



- IMAQ Overlay Line—Overlays a line on an image. Specify a line by its start and end points.



- IMAQ Overlay Multiple Lines—Overlays multiple lines on an image.



- IMAQ Overlay Rectangle—Overlays a rectangle on an image.



- IMAQ Overlay Oval—Overlays an oval or a circle on the image.



- IMAQ Overlay Arc—Overlays an arc on the image.



- IMAQ Overlay Bitmap—Overlays a bitmap on the image.



- IMAQ Overlay Text—Overlays text on an image.



- IMAQ Overlay ROI—Overlays an ROI described by the ROI Descriptor on an image.

To use these VIs, pass in the image on which you want to overlay information and the information that you want to overlay. You can also select the color of the overlay.

You can configure the following processing VIs to overlay different types of information on the inspection image:



- IMAQ Find Vertical Edge (**Machine Vision»Locate Edges**)



- IMAQ Find Horizontal Edge (**Machine Vision»Locate Edges**)



- IMAQ Find Circular Edge (**Machine Vision»Locate Edges**)



- IMAQ Find Concentric Edge (**Machine Vision»Locate Edges**)



- IMAQ Clamp Horizontal Max (**Machine Vision»Measure Distances**)



- IMAQ Clamp Horizontal Min (**Machine Vision»Measure Distances**)



- IMAQ Clamp Vertical Max (**Machine Vision»Measure Distances**)



- IMAQ Clamp Vertical Min (**Machine Vision»Measure Distances**)



- IMAQ Find Pattern (**Machine Vision»Find Patterns**)



- IMAQ Count Object (**Machine Vision»Count and Measure Objects**)



- IMAQ Find CoordSys (Rect) (**Machine Vision»Coordinate Systems**)



- IMAQ Find CoordSys (2 Rects) (**Machine Vision»Coordinate Systems**)



- IMAQ Find CoordSys (Pattern) (**Machine Vision»Coordinate Systems**)

You can overlay the following information with all the above VIs except IMAQ Find Patterns:

- The search area input into the VI.
- The search lines used for edge detection.
- The edges detected along the search lines
- The result of the VI.

Select the information you want to overlay by activating a boolean at the input of the VI that corresponds to the information type. With IMAQ Find Patterns, you can overlay the search area and the result.



Use the IMAQ Clear Overlay VI (**Vision Utilities»Overlay**) to clear any previous overlay information from the image. Use the IMAQ Write Image and Vision Info VI (**Vision Utilities»Overlay**) to save an image with its overlay information to a file. You can read the information from the file into an image using the IMAQ Read Image and Vision Info VI (**Vision Utilities»Overlay**). As with calibration information, overlay information is removed from an image when the image size or orientation changes.

Calibration

This chapter describes how to calibrate your imaging system, save calibration information, and attach calibration information to an image.

After you set up your imaging system, you may want to calibrate your system. If your imaging setup is such that the camera axis is close to 90° from the object under inspection and your lens has no distortion, use simple calibration. With simple calibration, you do not need to learn a template. Instead, you define the distance between pixels in the horizontal and vertical directions using real-world units.

If your camera axis is not perpendicular to the object under inspection and your lens is distorted, use perspective and nonlinear distortion calibration to calibrate your system.

Perspective and Nonlinear Distortion Calibration

Perspective errors and lens aberrations cause images to appear distorted. This distortion misplaces information in an image, but it does not necessarily destroy the information in the image. Calibrate your imaging system if you need to compensate for perspective errors and nonlinear lens distortion.

Follow these general steps to calibrate your imaging system:

1. Define a calibration template.
2. Define a reference coordinate system.
3. Learn the calibration information.

After you calibrate your imaging setup, you can attach the calibration information to an image. See the [Attach Calibration Information](#) section of this chapter for more information. Then, depending on your needs, you can either apply the calibration information to convert pixel coordinates to real-world coordinates without correcting the image, or you can create a distortion-free image by correcting the image for perspective errors and lens aberrations. See Chapter 4, [Blob Analysis](#), and Chapter 5, [Machine Vision](#), for more information about applying calibration information before making measurements.

Define a Calibration Template

You can define a calibration template by supplying an image of a grid or providing a list of pixel coordinates and their corresponding real-world coordinates. This section discusses the grid method in detail.

A calibration template is a user-defined grid of circular dots. As shown in Figure 6-1, the grid has constant spacings in the x and y directions. You can use any grid, but follow these guidelines for best results:

- The displacement in the x and y directions should be equal ($dx = dy$).
- The dots should cover the entire desired working area.
- The radius of the dots should be 6–10 pixels.
- The center-to-center distance between dots should range from 18 to 32 pixels, as shown in Figure 6-1.
- The minimum distance between the edges of the dots should be 6 pixels, as shown in Figure 6-1.

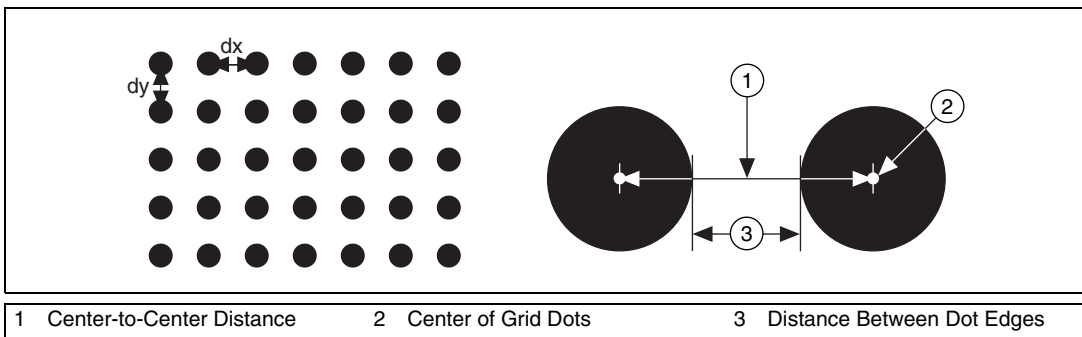


Figure 6-1. Defining a Calibration Grid



Note You can use the calibration grid installed with IMAQ Vision at **Start»Programs»National Instruments»Vision»Documentation»Calibration Grid**. The dots have radii of 2 mm and center-to-center distances of 1 cm. Depending on your printer, these measurements may change by a fraction of a millimeter. You can purchase highly accurate calibration grids from optics suppliers, such as Edmund Industrial Optics.

Define a Reference Coordinate System

To express measurements in real-world units, you need to define a coordinate system in the image of the grid. Define a coordinate system by its origin, angle, and axis direction.

The origin, expressed in pixels, defines the center of your coordinate system. The angle specifies the orientation of your coordinate system

with respect to the angle of the topmost row of dots in the grid image. The calibration procedure automatically determines the direction of the horizontal axis in the real world. The vertical axis direction can either be indirect, as shown in Figure 6-2a, or direct, as shown in Figure 6-2b.

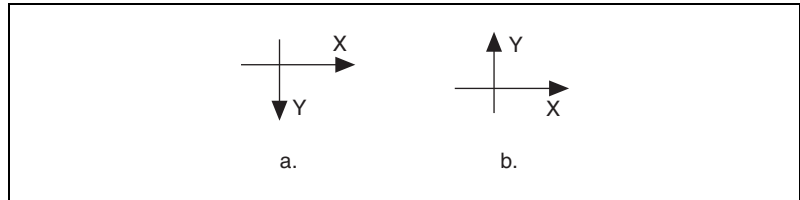


Figure 6-2. Axis Direction in the Image Plane

If you do not specify a coordinate system, the calibration process defines a default coordinate system. If you specify a grid for the calibration process, the software defines the following default coordinate system, as shown in Figure 6-3:

1. The origin is placed at the center of the left, topmost dot in the calibration grid.
2. The angle is set to 0° . This aligns the x-axis with the first row of dots in the grid, as shown in Figure 6-3b.
3. The axis direction is set to *indirect*. This aligns the y-axis to the first column of the dots in the grid, as shown in Figure 6-3b.

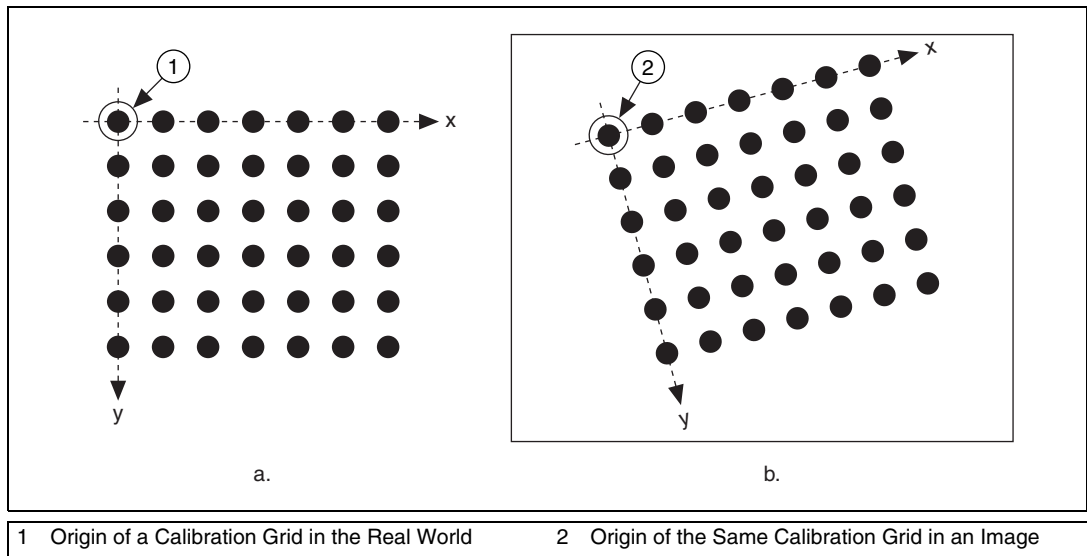


Figure 6-3. A Calibration Grid and an Image of the Grid



Note If you specify a list of points instead of a grid for the calibration process, the software defines a default coordinate system, as follows:

1. The origin is placed at the point in the list with the lowest x-coordinate value and then the lowest y-coordinate value.
2. The angle is set to 0° .
3. The axis direction is set to *indirect*.

If you define a coordinate system yourself, carefully consider the needs of your application. Remember the following:

- Express the origin in pixels. Always choose an origin location that lies within the calibration grid so that you can convert the location to real-world units.
- Specify the angle as the angle between the x-axis of the new coordinate system (x') and the top row of dots (x), as shown in Figure 6-4. If your imaging system exhibits nonlinear distortion, you cannot visualize the angle as you can in Figure 6-4 because the dots do not appear in straight lines.

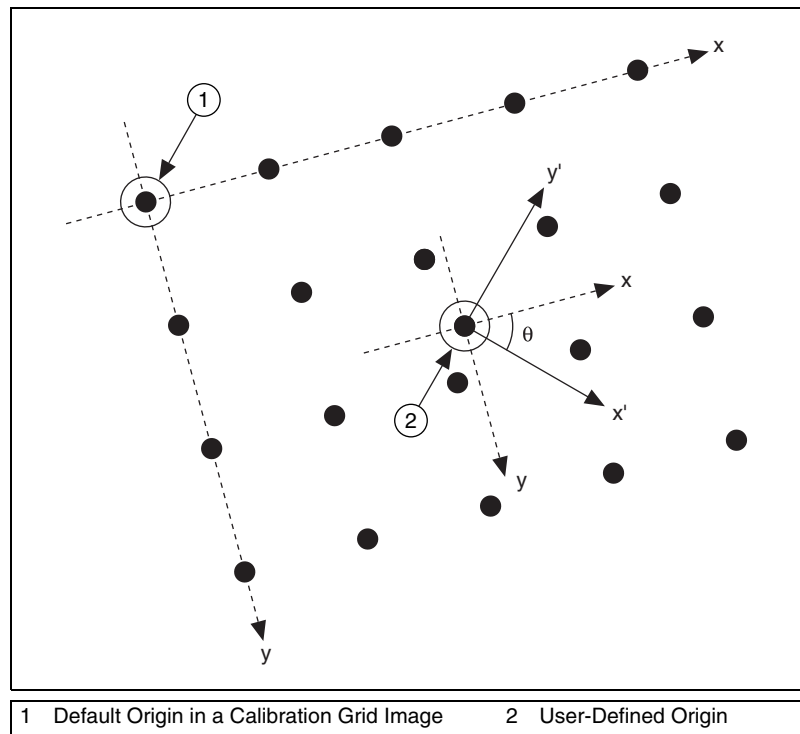


Figure 6-4. Defining a Coordinate System

Learn Calibration Information

After you define a calibration grid and reference axis, acquire an image of the grid using the current imaging setup. For information about acquiring images, see the *Acquire or Read an Image* section of Chapter 2, *Getting Measurement-Ready Images*. The grid does not need to occupy the entire image. You can choose a region within the image that contains the grid. After you acquire an image of the grid, learn the calibration information by inputting the image of the grid and the real-world distances between the dots into the IMAQ Learn Calibration Template VI (**Vision Utilities» Calibration**).



Note If you specified a list of points instead of a grid, the calibration software uses the pixel to real-world coordinate mapping to learn the calibration information.

Choose an ROI

Define a learning region of interest (ROI) during the learning process to define a region of the calibration grid you want to learn. The software ignores dot centers outside this region when it estimates the transformation. Creating a user-defined ROI is an effective way to increase correction speeds depending on the other calibration options selected.

Choose a Learning Algorithm

Select a method in which to learn the calibration information: perspective projection or nonlinear. Figure 6-5 illustrates the types of errors your image can exhibit. Figure 6-5a shows an image of a calibration grid with no errors. Figure 6-5b shows an image of a calibration grid with perspective projection. Figure 6-5c shows an image of a calibration grid with nonlinear distortion.

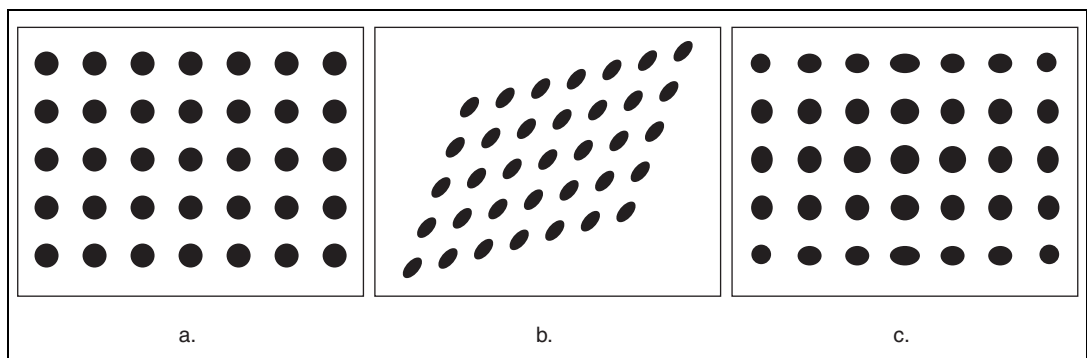


Figure 6-5. Types of Image Distortion

Choose perspective projection algorithm when your system exhibits perspective errors only. A perspective projection calibration has an accurate transformation even in areas not covered by the calibration grid, as shown in Figure 6-6. Learning and applying perspective projection is less computationally intensive than the nonlinear method. However, perspective projection cannot handle nonlinear distortions. If your imaging setup exhibits nonlinear distortion, use the nonlinear method. The nonlinear method guarantees accurate results only in the area that the calibration grid covers, as shown in Figure 6-6.

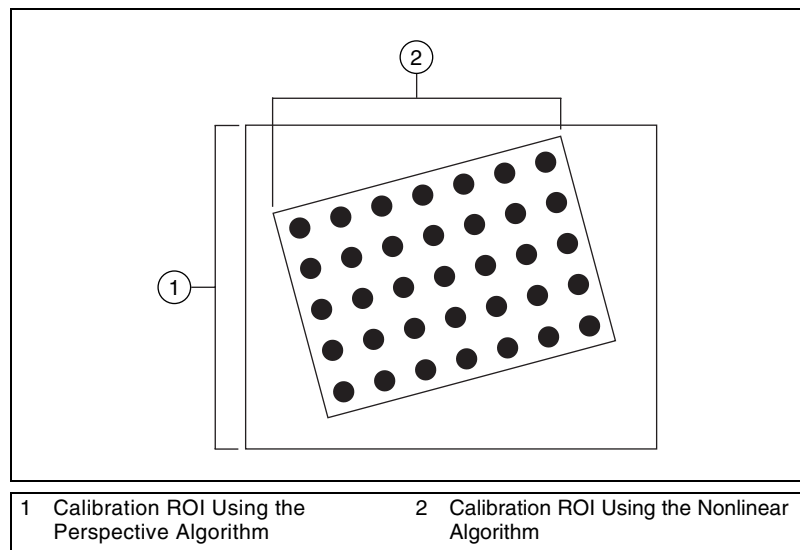


Figure 6-6. Calibration ROIs

Learning Score and Error Map

The learning process returns a score that reflects how well the software learned the input image. A high learning score indicates that you chose the appropriate learning algorithm, that the grid image complies with the guideline, and that your vision system setup is adequate.

If the learning process returns a low score, try the following:

1. Make sure your grid complies with the guidelines listed in the [Define a Calibration Template](#) section.
2. Check the lighting conditions. If you have too much or too little lighting, the software may estimate the center of the dots incorrectly.

Also, adjust your **Threshold Range** to distinguish the dots from the background.

3. Select another learning algorithm. When nonlinear lens distortion is present, using perspective projection sometimes results in a low learning score.



Note A high score does *not* reflect the accuracy of your system.

An error map helps you gauge the quality of your complete system. The error map returns an estimated error range to expect when a pixel coordinate is transformed into a real-world coordinate. The transformation accuracy may be higher than the value the error range indicates.

Correction Table

If the speed of image correction is a critical factor for your application, use a correction table. The correction table is a lookup table stored in memory that contains the real-world location information of all the pixels in the image. The extra memory requirements for this option are based on the size of the image. Use this option when you want to correct several images at a time in your vision application.

Scaling Mode

Use the scaling mode option to choose the appearance of the corrected image. Select either **Scale to Fit** or **Scale to Preserve Area**. For more information about the scaling mode, see Chapter 3, *System Setup and Calibration*, in the *IMAQ Vision Concepts Manual*.

Calibration Validation

Any image processing operation that changes the image size or orientation voids the calibration information in a calibrated image. Examples of VIs that void calibration information include IMAQ Resample, IMAQ Extract, IMAQ ArrayToImage, and IMAQ Unwrap.

Simple Calibration

When the axis of your camera is perpendicular to the image plane and lens distortion is negligible, use a simple calibration. In a simple calibration, a pixel coordinate is transformed to a real-world coordinate through scaling in the horizontal and vertical directions.

Map pixel coordinates to real-world coordinates directly without a calibration grid. The software rotates and scales a pixel coordinate according to predefined coordinate reference and scaling factors. You can assign the calibration to an arbitrary image using the IMAQ Set Simple Calibration VI (**Vision Utilities**»**Calibration**).



To perform a simple calibration, set a coordinate reference (angle, center, and axis direction) and scaling factors on the defined axis, as shown in Figure 6-7. Express the angle between the x-axis and the horizontal axis of the image in degrees. Express the center as the position, in pixels, where you want the coordinate reference origin. Set the axis direction to direct or indirect. Simple Calibration also offers a correction table option and a scaling mode option.

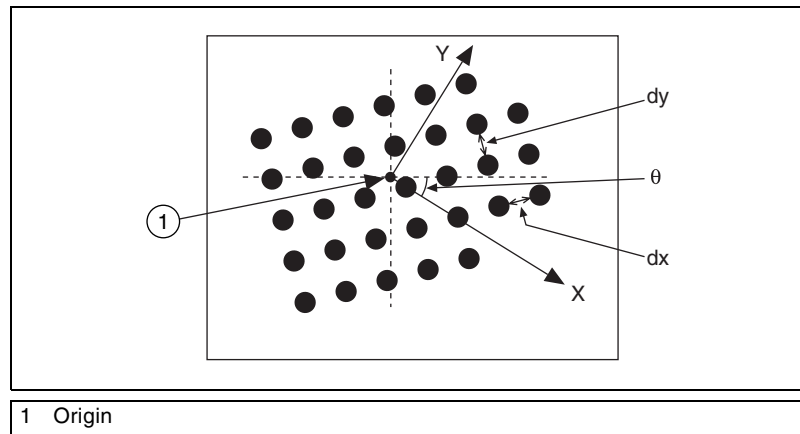


Figure 6-7. Defining a Simple Calibration

Save Calibration Information



After you learn the calibration information, you can save it so that you do not have to relearn the information for subsequent processing. Use the IMAQ Write Image and Vision Info VI (**Vision Utilities»Calibration**) to save the image of the grid and its associated calibration information to a file. To read the file containing the calibration information use the IMAQ Read Image and Vision Info VI (**Vision Utilities»Calibration**). For more information about attaching the calibration information you read from another image, see the [Attach Calibration Information](#) section.

Attach Calibration Information



Now that you have calibrated your setup correctly, you can apply the calibration settings to images that you acquire. Use the IMAQ Set Calibration Info VI (**Vision Utilities»Calibration**) to attach the calibration information of the current setup to each image you acquire. This VI takes in a source image containing the calibration information and a destination image that you want to calibrate. The output image is your inspection image with the calibration information attached to it.

Using the calibration information attached to the image, you can accurately convert pixel coordinates to real-world coordinates to make simple measurements, or you can correct the image by removing distortion to make shape measurements, such as blob analysis.



Note Because calibration information is part of the image, it is propagated throughout the processing and analysis of the image. Functions that modify the image size (such as an image rotation function) void the calibration information. Use IMAQ Write Image and Vision Info (**Vision Utilities»Calibration**) to save the image and all of the attached calibration information to a file.



Technical Support Resources

Web Support

National Instruments Web support is your first stop for help in solving installation, configuration, and application problems and questions. Online problem-solving and diagnostic resources include frequently asked questions, knowledge bases, product-specific troubleshooting wizards, manuals, drivers, software updates, and more. Web support is available through the Technical Support section of ni.com

NI Developer Zone

The NI Developer Zone at ni.com/zone is the essential resource for building measurement and automation systems. At the NI Developer Zone, you can easily access the latest example programs, system configurators, tutorials, technical news, as well as a community of developers ready to share their own techniques.

Customer Education

National Instruments provides a number of alternatives to satisfy your training needs, from self-paced tutorials, videos, and interactive CDs to instructor-led hands-on courses at locations around the world. Visit the Customer Education section of ni.com for online course schedules, syllabi, training centers, and class registration.

System Integration

If you have time constraints, limited in-house technical resources, or other dilemmas, you may prefer to employ consulting or system integration services. You can rely on the expertise available through our worldwide network of Alliance Program members. To find out more about our Alliance system integration solutions, visit the System Integration section of ni.com

Worldwide Support

National Instruments has offices located around the world to help address your support needs. You can access our branch office Web sites from the Worldwide Offices section of ni.com. Branch office Web sites provide up-to-date contact information, support phone numbers, e-mail addresses, and current events.

If you have searched the technical support resources on our Web site and still cannot find the answers you need, contact your local office or National Instruments corporate. Phone numbers for our worldwide offices are listed at the front of this manual.

Glossary

Prefix	Meaning	Value
m-	milli-	10^{-3}

Numbers/Symbols

1D	One-dimensional.
2D	Two-dimensional.
3D	Three-dimensional.
3D view	Displays the light intensity of an image in a three-dimensional coordinate system, where the spatial coordinates of the image form two dimensions and the light intensity forms the third dimension.

A

AIPD	National Instruments internal image file format used for saving complex images and calibration information associated with an image (extension APD).
alignment	The process by which a machine vision application determines the location, orientation, and scale of a part being inspected.
alpha channel	Channel used to code extra information, such as gamma correction, about a color image. The alpha channel is stored as the first byte in the four-byte representation of an RGB pixel.
area	A rectangular portion of an acquisition window or frame that is controlled and defined by software.
area threshold	Detects objects based on their size, which can fall within a user-specified range.
arithmetic operators	The image operations multiply, divide, add, subtract, and remainder.

array	Ordered, indexed set of data elements of the same type.
auto-median function	A function that uses dual combinations of opening and closing operations to smooth the boundaries of objects.

B

b	Bit. One binary digit, either 0 or 1.
B	Byte. Eight related bits of data, an eight-bit binary number. Also denotes the amount of memory required to store one byte of data.
barycenter	The grayscale value representing the centroid of the range of an image's grayscale values in the image histogram.
binary image	An image in which the objects usually have a pixel intensity of 1 (or 255) and the background has a pixel intensity of 0.
binary morphology	Functions that perform morphological operations on a binary image.
binary threshold	Separation of an image into objects of interest (assigned a pixel value of 1) and background (assigned pixel values of 0) based on the intensities of the image pixels.
bit depth	The number of bits (n) used to encode the value of a pixel. For a given n , a pixel can take 2^n different values. For example, if n equals 8-bits, a pixel can take 256 different values ranging from 0 to 255. If n equals 16 bits, a pixel can take 65,536 different values ranging from 0 to 65,535 or $-32,768$ to 32,767.
black reference level	The level that represents the darkest an image can get. <i>See also</i> white reference level .
blob	Binary large object. A connected region or grouping of pixels in an image in which all pixels have the same intensity level.
blob analysis	A series of processing operations and analysis functions that produce some information about the blobs in an image.
blurring	Reduces the amount of detail in an image. Blurring commonly occurs because the camera is out of focus. You can blur an image intentionally by applying a lowpass frequency filter.

BMP	Bitmap. Image file format commonly used for 8-bit and color images (extension BMP).
border function	Removes objects (or particles) in a binary image that touch the image border.
brightness	(1) A constant added to the red, green, and blue components of a color pixel during the color decoding process. (2) The perception by which white objects are distinguished from gray and light objects from dark objects.
buffer	Temporary storage for acquired data.
C	
caliper	(1) A function in IMAQ Vision Builder that calculates distances, angles, circular fits, and the center of mass based on positions given by edge detection, particle analysis, centroid, and search functions. (2) A measurement function that finds edge pairs along a specified path in the image. This function performs an edge extraction and then finds edge pairs based on specified criteria such as the distance between the leading and trailing edges, edge contrasts, and so forth.
center of mass	The point on an object where all the mass of the object could be concentrated without changing the first moment of the object about any axis
character recognition	The ability of a machine to read human-readable text.
chroma	The color information in a video signal.
chromaticity	The combination of hue and saturation. The relationship between chromaticity and brightness characterizes a color.
circle function	Detects circular objects in a binary image.
closing	A dilation followed by an erosion. A closing fills small holes in objects and smooths the boundaries of objects.
clustering	Technique where the image is sorted within a discrete number of classes corresponding to the number of phases perceived in an image. The gray values and a barycenter are determined for each class. This process is repeated until a value is obtained that represents the center of mass for each phase or class.

CLUT	Color lookup table. Table for converting the value of a pixel in an image into a red, green, and blue (RGB) intensity.
color images	Images containing color information, usually encoded in the RGB form.
color space	The mathematical representation for a color. For example, color can be described in terms of red, green, and blue; hue, saturation, and luminance; or hue, saturation, and intensity.
complex image	Stores information obtained from the FFT of an image. The complex numbers that compose the FFT plane are encoded in 64-bit floating-point values: 32bits for the real part and 32bits for the imaginary part.
connectivity	Defines which of the surrounding pixels of a given pixel constitute its neighborhood.
connectivity-4	Only pixels adjacent in the horizontal and vertical directions are considered neighbors.
connectivity-8	All adjacent pixels are considered neighbors.
contrast	A constant multiplication factor applied to the luma and chroma components of a color pixel in the color decoding process.
convex function	Computes the convex regions of objects in a binary image.
convex hull	The smallest convex polygon that can encapsulate a particle.
convolution	See linear filter .
convolution kernel	2D matrices (or templates) used to represent the filter in the filtering process. The contents of these kernels are a discrete two-dimensional representation of the impulse response of the filter that they represent.
cross correlation	The most common way to perform pattern matching.

D

Danielsson function	Similar to the distance functions, but with more accurate results.
dB	Decibel. The unit for expressing a logarithmic measure of the ratio of two signal levels: $\text{dB} = 20\log_{10} V1/V2$, for signals in volts.

default setting	A default parameter value recorded in the driver. In many cases, the default input of a control is a certain value (often 0).
definition	The number of values a pixel can take on, which is the number of colors or shades that you can see in the image.
dendrite	Branches of the skeleton of an object.
densitometry	Determination of optical or photographic density.
density function	For each gray level in a linear histogram, the function gives the number of pixels in the image that have the same gray level.
differentiation filter	Extracts the contours (edge detection) in gray level.
digital image	An image $f(x, y)$ that has been converted into a discrete number of pixels. Both spatial coordinates and brightness are specified.
dilation	Increases the size of an object along its boundary and removes tiny holes in the object.
distance calibration	Determination of the physical dimensions of a pixel by defining the physical dimensions of a line in the image.
distance function	Assigns to each pixel in an object a gray-level value equal to its shortest Euclidean distance from the border of the object.
driver	Software that controls a specific hardware device, such as an IMAQ or DAQ device.
dynamic range	The ratio of the largest signal level a circuit can handle to the smallest signal level it can handle (usually taken to be the noise level), normally expressed in decibels.

E

edge	Defined by a sharp change (transition) in the pixel intensities in an image or along an array of pixels.
edge contrast	The difference between the average pixel intensity before and the average pixel intensity after the edge.
edge detection	Any of several techniques to identify the edges of objects in an image.

edge hysteresis	The difference in threshold level between a rising and a falling edge.
edge steepness	The number of pixels that corresponds to the slope or transition area of an edge.
energy center	The center of mass of a grayscale image. <i>See</i> center of mass .
entropy	A measure of the randomness in an image. An image with high entropy contains more pixel value variation than an image with low entropy.
equalize function	<i>See</i> histogram equalization .
erosion	Reduces the size of an object along its boundary and eliminates isolated points in the image.
Euclidean distance	The shortest distance between two points in a Cartesian system.
exponential and gamma corrections	Expand the high gray-level information in an image while suppressing low gray-level information.
exponential function	Decreases brightness and increases contrast in bright regions of an image, and decreases contrast in dark regions of an image.

F

FFT	Fast Fourier Transform. A method used to compute the Fourier transform of an image.
fiducial	A reference pattern on a part that helps a machine vision application find the part's location and orientation in an image.
form	Window or area on the screen on which you place controls and indicators to create the user interface for your program.
Fourier spectrum	The magnitude information of the Fourier transform of an image.
Fourier transform	Transforms an image from the spatial domain to the frequency domain.
frequency filters	Counterparts of spatial filters in the frequency domain. For images, frequency information is in the form of spatial frequency.

ft	Feet.
function	A set of software instructions executed by a single line of code that may have input and/or output parameters and returns a value when executed.
G	
gamma	The nonlinear change in the difference between the video signal's brightness level and the voltage level needed to produce that brightness.
gauging	Measurement of an object or distances between objects.
Gaussian filter	A filter similar to the smoothing filter, but using a Gaussian kernel in the filter operation. The blurring in a Gaussian filter is more gentle than a smoothing filter.
gradient convolution filter	See gradient filter .
gradient filter	Extracts the contours (edge detection) in gray-level values. Gradient filters include the Prewitt and Sobel filters.
gray level	The brightness of a pixel in an image.
gray-level dilation	Increases the brightness of pixels in an image that are surrounded by other pixels with a higher intensity.
gray-level erosion	Reduces the brightness of pixels in an image that are surrounded by other pixels with a lower intensity.
grayscale image	An image with monochrome information.
grayscale morphology	Functions that perform morphological operations on a gray-level image.
H	
h	Hour.
highpass attenuation	Inverse of lowpass attenuation.
highpass FFT filter	Removes or attenuates low frequencies present in the FFT domain of an image.

highpass filter	Emphasizes the intensity variations in an image, detects edges (or object boundaries), and enhances fine details in an image.
highpass frequency filter	Attenuates or removes (truncates) low frequencies present in the frequency domain of the image. A highpass frequency filter suppresses information related to slow variations of light intensities in the spatial image.
highpass truncation	Inverse of lowpass truncation.
histogram	Indicates the quantitative distribution of the pixels of an image per gray-level value.
histogram equalization	Transforms the gray-level values of the pixels of an image to occupy the entire range (0 to 255 in an 8-bit image) of the histogram, increasing the contrast of the image.
histogram inversion	Finds the photometric negative of an image. The histogram of a reversed image is equal to the original histogram flipped horizontally around the center of the histogram.
histograph	In LabVIEW, a histogram that can be wired directly into a graph.
hit-miss function	Locates objects in the image similar to the pattern defined in the structuring element.
hole filling function	Fills all holes in objects that are present in a binary image.
HSI	Color encoding scheme in Hue, Saturation, and Intensity.
HSL	Color encoding scheme using Hue, Saturation, and Luminance information where each image in the pixel is encoded using 32 bits: 8 bits for hue, 8 bits for saturation, 8 bits for luminance, and 8 unused bits.
HSV	Color encoding scheme in Hue, Saturation, and Value.
hue	Represents the dominant color of a pixel. The hue function is a continuous function that covers all the possible colors generated using the R, G, and B primaries. <i>See also</i> RGB .
hue offset angle	The value added to all hue values so that the discontinuity occurs outside the values of interest during analysis.
Hz	Hertz. Frequency in units of 1/second.

I

I/O	Input/output. The transfer of data to/from a computer system involving communications channels, operator interface devices, and/or data acquisition and control interfaces.
image	A two-dimensional light intensity function $f(x, y)$ where x and y denote spatial coordinates and the value f at any point (x, y) is proportional to the brightness at that point.
image border	A user-defined region of pixels surrounding an image. Functions that process pixels based on the value of the pixel neighbors require image borders.
Image Browser	An image that contains thumbnails of images to analyze or process in a vision application.
image buffer	Memory location used to store images.
image definition	See pixel depth .
image enhancement	The process of improving the quality of an image that you acquire from a sensor in terms of signal-to-noise ratio, image contrast, edge definition, and so on.
image file	A file containing pixel data and additional information about the image.
image format	Defines how an image is stored in a file. Usually composed of a header followed by the pixel data.
image mask	A binary image that isolates parts of a source image for further processing. A pixel in the source image is processed if its corresponding mask pixel has a non-zero value. A source pixel whose corresponding mask pixel has a value of 0 is left unchanged.
image palette	The gradation of colors used to display an image on screen, usually defined by a color lookup table.
image processing	Encompasses various processes and analysis functions that you can apply to an image.
image source	Original input image.
image understanding	A technique that interprets the content of the image at a symbolic level rather than a pixel level.

image visualization	The presentation (display) of an image (image data) to the user.
imaging	Any process of acquiring and displaying images and analyzing image data.
IMAQ	Image Acquisition.
in.	Inches.
INL	Integral nonlinearity. A measure in LSB of the worst-case deviation from the ideal A/D or D/A transfer characteristic of the analog I/O circuitry.
inner gradient	Finds the inner boundary of objects.
inspection	The process by which parts are tested for simple defects such as missing parts or cracks on part surfaces.
inspection function	Analyzes groups of pixels within an image and returns information about the size, shape, position, and pixel connectivity. Typical applications include quality of parts, analyzing defects, locating objects, and sorting objects.
instrument driver	A set of high-level software functions, such as NI-IMAQ, that control specific plug-in computer boards. Instrument drivers are available in several forms, ranging from a function callable from a programming language to a virtual instrument (VI) in LabVIEW.
intensity	The sum of the Red, Green, and Blue primary colors divided by three, $(Red + Green + Blue)/3$.
intensity calibration	Assigning user-defined quantities such as optical densities or concentrations to the gray-level values in an image.
intensity profile	The gray-level distribution of the pixels along an ROI in an image.
intensity range	Defines the range of gray-level values in an object of an image.
intensity threshold	Characterizes an object based on the range of gray-level values in the object. If the intensity range of the object falls within the user-specified range, it is considered an object. Otherwise it is considered part of the background.
interpolation	The technique used to find values in between known values when resampling an image or array of pixels.

IRE A relative unit of measure (named for the Institute of Radio Engineers). 0 IRE corresponds to the blanking level of a video signal, 100 IRE to the white level. Note that for CCIR/PAL video, the black level is equal to the blanking level or 0 IRE, while for RS-170/NTSC video, the black level is at 7.5 IRE.

J

JPEG Joint Photographic Experts Group. Image file format for storing 8-bit and color images with lossy compression (extension JPG).

K

k Kilo. The standard metric prefix for 1,000, or 10^3 , used with units of measure such as volts, hertz, and meters.

K Kilo. The prefix for 1,024, or 2^{10} , used with B in quantifying data or computer memory.

kernel Structure that represents a pixel and its relationship to its neighbors. The relationship is specified by weighted coefficients of each neighbor.

L

labeling The process by which each object in a binary image is assigned a unique value. This process is useful for identifying the number of objects in the image and giving each object a unique identity.

LabVIEW Laboratory Virtual Instrument Engineering Workbench. Program development environment application based on the programming language G used commonly for test and measurement applications.

Laplacian filter Extracts the contours of objects in the image by highlighting the variation of light intensity surrounding a pixel.

line gauge Measures the distance between selected edges with high-precision subpixel accuracy along a line in an image. For example, this function can be used to measure distances between points and edges. This function also can step and repeat its measurements across the image.

line profile Represents the gray-level distribution along a line of pixels in an image.

linear filter	A special algorithm that calculates the value of a pixel based on its own pixel value as well as the pixel values of its neighbors. The sum of this calculation is divided by the sum of the elements in the matrix to obtain a new pixel value.
logarithmic and inverse gamma corrections	Expand low gray-level information in an image while compressing information from the high gray-level ranges.
logarithmic function	Increases the brightness and contrast in dark regions of an image and decreases the contrast in bright regions of the image.
logic operators	The image operations AND, NAND, OR, XOR, NOR, XNOR, difference, mask, mean, max, and min.
lossless compression	Compression in which the decompressed image is identical to the original image.
lossy compression	Compression in which the decompressed image is visually similar but not identical to the original image.
lowpass attenuation	Applies a linear attenuation to the frequencies in an image, with no attenuation at the lowest frequency and full attenuation at the highest frequency.
lowpass FFT filter	Removes or attenuates high frequencies present in the FFT domain of an image.
lowpass filter	Attenuates intensity variations in an image. You can use these filters to smooth an image by eliminating fine details and blurring edges.
lowpass frequency filter	Attenuates high frequencies present in the frequency domain of the image. A lowpass frequency filter suppresses information related to fast variations of light intensities in the spatial image.
lowpass truncation	Removes all frequency information above a certain frequency.
LSB	Least significant bit.
L-skeleton function	Uses an L-shaped structuring element in the skeleton function.
luma	The brightness information in the video picture. The luma signal amplitude varies in proportion to the brightness of the video signal and corresponds exactly to the monochrome picture.
luminance	See luma .

LUT	Lookup table. Table containing values used to transform the gray-level values of an image. For each gray-level value in the image, the corresponding new value is obtained from the lookup table.
M	
m	Meters.
M	(1) Mega, the standard metric prefix for 1 million or 10^6 , when used with units of measure such as volts and hertz (2) Mega, the prefix for 1,048,576, or 220, when used with B to quantify data or computer memory.
machine vision	An automated application that performs a set of visual inspection tasks.
mask FFT filter	Removes frequencies contained in a mask (range) specified by the user.
match score	A number ranging from 0 to 1000 that indicates how closely an acquired image matches the template image. A match score of 1000 indicates a perfect match. A match score of 0 indicates no match.
MB	Megabyte of memory.
median filter	A lowpass filter that assigns to each pixel the median value of its neighbors. This filter effectively removes isolated pixels without blurring the contours of objects.
memory buffer	See buffer .
mile	An Imperial unit of length equal to 5,280 feet or 1,609.344 meters. Also known as a statute mile to discern from a nautical mile. See also nautical mile .
MMX	Multimedia Extensions. Intel chip-based technology that allows parallel operations on integers, which results in accelerated processing of 8-bit images.
morphological transformations	Extract and alter the structure of objects in an image. You can use these transformations for expanding (dilating) or reducing (eroding) objects, filling holes, closing inclusions, or smoothing borders. They are used primarily to delineate objects and prepare them for quantitative inspection analysis.

MSB	Most significant bit.
M-skeleton function	Uses an M-shaped structuring element in the skeleton function.

N

nautical mile	International unit of length used for sea and air navigation equal to 6,076.115 feet or 1,852 meters. <i>See also</i> mile .
neighbor	A pixel whose value affects the value of a nearby pixel when an image is processed. The neighbors of a pixel are usually defined by a kernel or a structuring element.
neighborhood operations	Operations on a point in an image that take into consideration the values of the pixels neighboring that point.
NI-IMAQ	Driver software for National Instruments IMAQ hardware.
nonlinear filter	Replaces each pixel value with a nonlinear function of its surrounding pixels.
nonlinear gradient filter	A highpass edge-extraction filter that favors vertical edges.
nonlinear Prewitt filter	A highpass, edge-extraction filter based on two-dimensional gradient information.
nonlinear Sobel filter	A highpass, edge-extraction filter based on two-dimensional gradient information. The filter has a smoothing effect that reduces noise enhancements caused by gradient operators.
Nth order filter	Filters an image using a nonlinear filter. This filter orders (or classifies) the pixel values surrounding the pixel being processed. The pixel being processed is set to the Nth pixel value, where N is the order of the filter.
number of planes (in an image)	The number of arrays of pixels that compose the image. A gray-level or pseudo-color image is composed of one plane, while an RGB image is composed of three planes (one for the red component, one for the blue, and one for the green).

O

offset	The coordinate position in an image where you want to place the origin of another image. Setting an offset is useful when performing mask operations.
opening	An erosion followed by a dilation. An opening removes small objects and smooths boundaries of objects in the image.
operators	Allow masking, combination, and comparison of images. You can use arithmetic and logic operators in IMAQ Vision.
optical character verification	A machine vision application that inspects the quality of printed characters.
optical representation	Contains the low-frequency information at the center and the high-frequency information at the corners of an FFT-transformed image.
outer gradient	Finds the outer boundary of objects.

P

palette	The gradation of colors used to display an image on screen, usually defined by a color lookup table.
pattern matching	The technique used to locate quickly a grayscale template within a grayscale image
picture aspect ratio	The ratio of the active pixel region to the active line region. For standard video signals like RS-170 or CCIR, the full-size picture aspect ratio normally is 4/3 (1.33).
picture element	An element of a digital image. Also called pixel.
pixel	Picture element. The smallest division that makes up the video scan line. For display on a computer monitor, a pixel's optimum dimension is square (aspect ratio of 1:1, or the width equal to the height).
pixel aspect ratio	The ratio between the physical horizontal size and the vertical size of the region covered by the pixel. An acquired pixel should optimally be square, thus the optimal value is 1.0, but typically it falls between 0.95 and 1.05, depending on camera quality.
pixel calibration	Directly calibrating the physical dimensions of a pixel in an image.

pixel depth	The number of bits used to represent the gray level of a pixel.
PNG	Portable Network Graphic. Image file format for storing 8-bit, 16-bit, and color images with lossless compression (extension PNG).
power 1/Y function	Similar to a logarithmic function but with a weaker effect.
power Y function	See exponential function .
Prewitt filter	Extracts the contours (edge detection) in gray-level values using a 3 x 3 filter kernel.
probability function	Defines the probability that a pixel in an image has a certain gray-level value.
proper-closing	A finite combination of successive closing and opening operations that you can use to fill small holes and smooth the boundaries of objects.
proper-opening	A finite combination of successive opening and closing operations that you can use to remove small particles and smooth the boundaries of objects.
pts	Points.
pyramidal matching	A technique used to increase the speed of a pattern matching algorithm by matching subsampled versions of the image and the reference pattern.
Q	
quantitative analysis	Obtaining various measurements of objects in an image.
R	
real time	A property of an event or system in which data is processed as it is acquired instead of being accumulated and processed at a later time.
relative accuracy	A measure in LSB of the accuracy of an ADC; it includes all nonlinearity and quantization errors but does not include offset and gain errors of the circuitry feeding the ADC.
resolution	The number of rows and columns of pixels. An image composed of m rows and n columns has a resolution of

reverse function	Inverts the pixel values in an image, producing a photometric negative of the image.
RGB	Color encoding scheme using red, green, and blue (RGB) color information where each pixel in the color image is encoded using 32 bits: 8 bits for red, 8 bits for green, 8 bits for blue, and 8 bits for the alpha value (unused).
Roberts filter	Extracts the contours (edge detection) in gray level, favoring diagonal edges.
ROI	Region of interest. (1) An area of the image that is graphically selected from a window displaying the image. This area can be used focus further processing. (2) A hardware-programmable rectangular portion of the acquisition window.
ROI tools	Collection of tools from the Lab VIEW Tools palette that enable you to select a region of interest from an image. These tools let you select a point or line; polygon, rectangle, and oval regions; and freehand lines and areas.
rotational shift	The amount by which one image is rotated with respect to a reference image. This rotation is computed with respect to the center of the image.
rotation-invariant matching	A pattern matching technique in which the reference pattern can be located at any orientation in the test image as well as rotated at any degree.
S	
s	Seconds.
saturation	The amount of white added to a pure color. Saturation relates to the richness of a color. A saturation of zero corresponds to a pure color with no white added. Pink is a red with low saturation.
scale-invariant matching	A pattern matching technique in which the reference pattern can be any size in the test image.
segmentation function	Fully partitions a labeled binary image into non-overlapping segments, with each segment containing a unique object.
separation function	Separates objects that touch each other by narrow isthmuses.
shape matching	Finds objects in an image whose shape matches the shape of the object specified by a shape template. The matching process is invariant to rotation and can be set to be invariant to the scale of the objects.

shift-invariant matching	A pattern matching technique in which the reference pattern can be located anywhere in the test image but cannot be rotated or scaled.
Sigma filter	A highpass filter that outlines edges.
skeleton function	Applies a succession of thinning operations to an object until its width becomes one pixel.
skiz function	Obtains lines in an image that separate each object from the others and are equidistant from the objects that they separate.
smoothing filter	Blurs an image by attenuating variations of light intensity in the neighborhood of a pixel.
Sobel filter	Extracts the contours (edge detection) in gray-level values using a 3×3 filter kernel.
spatial calibration	Assigning physical dimensions to the area of a pixel in an image.
spatial filters	Alter the intensity of a pixel with respect to variations in intensities of its neighboring pixels. You can use these filters for edge detection, image enhancement, noise reduction, smoothing, and so forth.
spatial resolution	The number of pixels in an image, in terms of the number of rows and columns in the image.
square function	See exponential function .
square root function	See logarithmic function .
standard representation	Contains the low-frequency information at the corners and high-frequency information at the center of an FFT-transformed image.
statute mile	See mile .
structuring element	A binary mask used in most morphological operations. A structuring element is used to determine which neighboring pixels contribute in the operation.
sub-pixel analysis	Finds the location of the edge coordinates in terms of fractions of a pixel.

T

template	Color, shape, or pattern that you are trying to match in an image using the color matching, shape matching, or pattern matching functions. A template can be a region selected from an image or it can be an entire image.
thickening	Alters the shape of objects by adding parts to the object that match the pattern specified in the structuring element.
thinning	Alters the shape of objects by eliminating parts of the object that match the pattern specified in the structuring element.
threshold	Separates objects from the background by assigning all pixels with intensities within a specified range to the object and the rest of the pixels to the background. In the resulting binary image, objects are represented with a pixel intensity of 255 and the background is set to 0.
threshold interval	Two parameters, the lower threshold gray-level value and the upper threshold gray-level value.
TIFF	Tagged Image File Format. Image format commonly used for encoding 8-bit, 16-bit, and color images (extension TIF).
Tools palette	Collection of tools that enable you to select regions of interest, zoom in and out, and change the image palette.
truth table	A table associated with a logic operator that describes the rules used for that operation.

V

V	Volts.
value	The grayscale intensity of a color pixel computed as the average of the maximum and minimum red, green, and blue values of that pixel.
VI	Virtual Instrument. (1) A combination of hardware and/or software elements, typically used with a PC, that has the functionality of a classic stand-alone instrument (2) A LabVIEW software module (VI), which consists of a front panel user interface and a block diagram program.

W

- watershed A technique used to segment an image into multiple regions.
- white reference level The level that defines what is white for a particular video system. *See also* [black reference level](#).

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