Image Acquisition Fundamentals

I. Cameras

You can choose between two main types of cameras: analog and digital. Digital cameras can be further classified into parallel digital, Camera Link, and IEEE-1394. The following sections contain information about these cameras and their advantages and disadvantages, which can help you choose the right camera for your application.

Analog Cameras

Analog cameras are cameras that output a video signal in analog format. The analog signal is digitized by an image acquisition board. The video signal is based on the television standard, making analog the most common standard for representing video signals.

You may have heard the term charge-coupled device (CCD), and wondered how it relates to the analog video signal. A CCD is an array of hundreds of thousands of interconnected semiconductors. Each pixel is a solid-state, photosensitive element that generates and stores an electric charge when it is illuminated. The pixel is the building block for the CCD imager, a rectangular array of pixels on which an image of the scene is focused. In most configurations, the sensor includes the circuitry that stores and transfers its charge to a shift register, which converts the spatial array of charges in the CCD imager into a time-varying video signal. Timing information for the vertical and horizontal positions and the sensor value combine to form the video signal.

For standard analog cameras, the lines of the CCD are interlaced to increase the perceived image update rate. This means that the odd numbered rows (the odd field) are scanned first. Then the even numbered fields (the even field) are scanned. The two fields make up one frame. Electronic Industries Association (EIA) RS-170 and NTSC cameras update at 30 frames/s with a resolution of 640 columns x 480 rows. CCIR and PAL cameras update at 25 frames/s with a resolution of 768 columns x 576 rows.

Analog cameras are low cost and easy to interface with a standard analog acquisition device. Therefore, they can solve numerous applications at an attractive price.

Digital Cameras

Digital cameras have several advantages over analog cameras. Analog video is more susceptible to noise during transmission than digital video. By digitizing at the camera level rather than at the image acquisition board, the signal-to-noise ratio is typically higher, resulting in better accuracy. Because digital cameras are not required to support television standards, they can support larger image sizes and faster frame rates, as well as higher pixel resolutions. Digital cameras come with 10-bit to 16-bit gray levels of resolution as a standard for machine vision, astronomy, microscopy, and thermal imaging applications. Digital cameras use the same CCD type devices for acquiring images as analog, they simply digitize the video before sending it to the frame grabber.

Parallel Digital Cameras

Until recently, parallel digital cameras were the only type of digital cameras available. They offer all of the benefits mentioned above. However, parallel digital cameras have no clear physical or protocol standards, and interfacing to digital acquisition devices can be difficult. Parallel digital cameras often require custom cables to connect with image acquisition boards. Also, you must be certain that your camera is compatible with your image acquisition device.

Fortunately, a large base of parallel cameras exists on the market for almost any imaging application. National Instruments provides cables and camera configuration files to make connecting to parallel digital cameras easy. To determine whether one of National Instruments' acquisition devices supports your camera, visit Camera Advisor on ni.com/vision.

Camera Link

Camera Link is an interface specification for cables that connect digital cameras to image acquisition boards. It preserves the benefits of digital cameras--such as flexibility for many types of sensors--yet it has only a small connector and one or two identical cables, which work with all Camera Link image acquisition devices. Camera Link greatly simplifies cabling, which can be a complex task when working with standard digital cameras. To determine whether one of National Instruments' acquisition devices supports your camera, visit Camera Advisor on ni.com.

IEEE 1394

IEEE 1394 is a serial bus standard used by many PC peripherals, including digital cameras. IEEE 1394 cameras use a simple, flexible, 4-wire or 6-wire power cable; and in some cases, the bus can supply power to the camera. However, because IEEE 1394 is a shared bus, there is a bandwidth limitation of ~40 MB/s when no other device is connected to the bus. IEEE 1394 cameras also require processor control to move the image data, which limits available processor bandwidth for image processing.

IEEE 1394 is a standard that also includes functions for enumerating and setting up the camera capabilities. You can acquire images from any industrial IEEE 1394 camera and OHCI-compliant IEEE 1394 adapter using National Instruments NI-IMAQ for IEEE 1394 Cameras driver software, which you can purchase at ni.com.

II. Important Camera Technologies

Progressive Scan

In standard analog cameras, the CCD is exposed and read in two fields: the odd field and the even field. When imaging an object in motion, the interlacing of the odd and even fields of the CCD sensor causes a double exposure of the image, as shown in Figure 1.

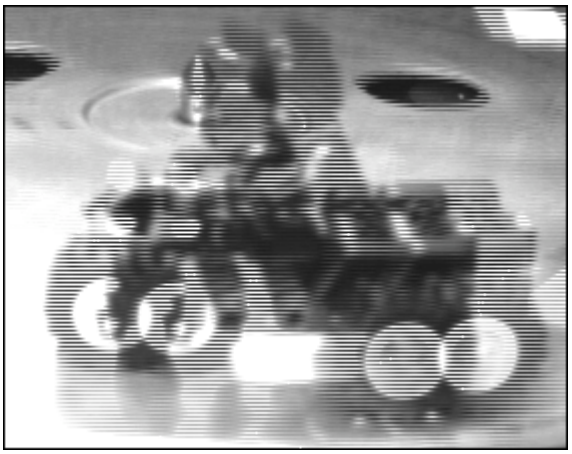

Figure 1. Images of a Moving Object Taken with a Standard Analog Camera

In progressive scan cameras, the CCD sensor array is exposed at the same time rather than in two steps. This behavior makes progressive scan cameras especially useful in applications where the object under inspection moves. However, you need to set the appropriate exposure time in order to acquire images without motion-induced blur. Figures 2a, 2b, and 2c are images of a moving toy motorcycle taken with a progressive scan camera using exposure times of 33 ms, 10 ms, and 1 ms, respectively.

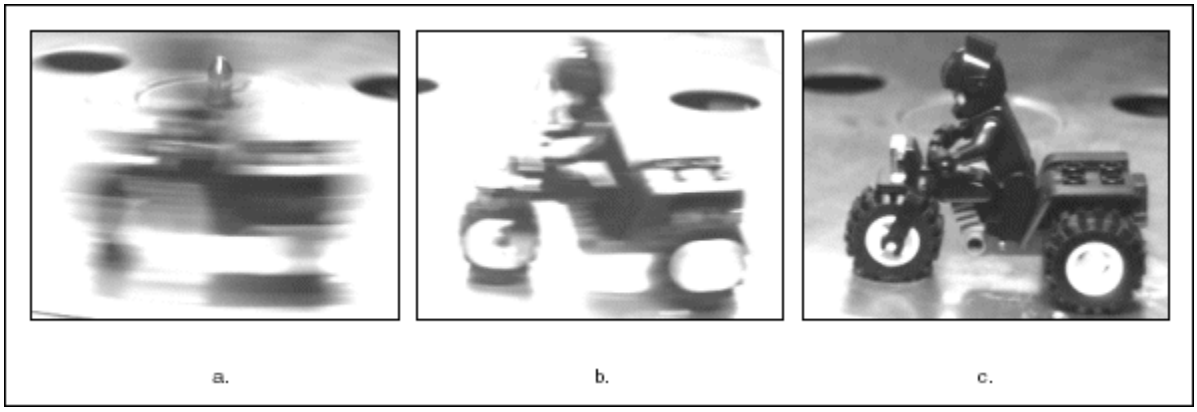

Figure 2. Images of a moving toy motorcycle taken with a progressive scan camera using exposure times of 33 ms, 10 ms, and 1 ms, respectively

National Instruments PCI/PXI-1407 and PCI-1409 image acquisition boards work with progressive scan and standard analog cameras.

Line Scan

Unlike an area scan camera, which acquires a two-dimensional image, a line scan camera acquires an image that is only one pixel wide. Figure 3 illustrates the concept of a line scan camera acquiring images of a bolt one "line" (or pixel) at a time.

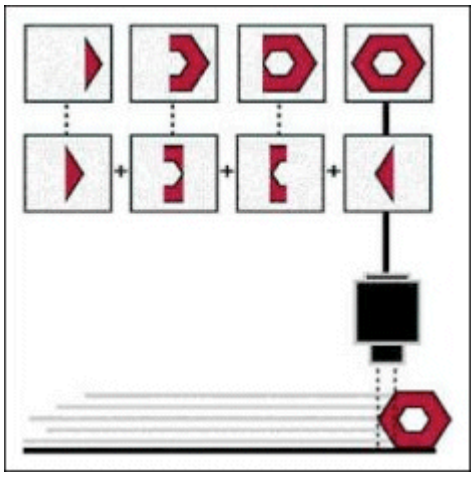

Figure 3. Concept of a Line Scan Acquisition

Line scan cameras are useful in web inspection applications during which the object under inspection moves along a conveyor or stage in a production system. Line scan cameras are also useful in high-resolution applications because you can acquire lines at a fast rate as the part moves. You can use the PCI-1424, PCI-1428 , and PCI-1422/PXI-1422 boards with digital line scan cameras, as well as the PCI-1409 with analog line scan cameras. The width of Line Scan cameras is fixed by the number of CCDs in the camera, but the NI-IMAQ driver allows you to make the image height arbitrary (must fit in on-board memory - 32MBytes to 80 MBytes) depending on the size of the object to inspect. This is called Variable Height Acquisition (VHA).

Infrared

Infrared, or thermal, cameras measure the thermal, or infrared, energy emitted from a scene. Infrared cameras can help solve some scientific and industrial applications that sensors using the visible spectrum of light cannot solve. You can see many defects easier in the infrared spectrum. You can also measure the contents of containers if the contents are a different temperature than the container. For example, you can use an infrared camera to see the oil level in a compressor when the oil temperature differs from the casing temperature.

National Instruments products make it simple to acquire and process thermal images. Using IMAQ devices, you can acquire images from infrared cameras, including some high-resolution digital cameras. Then you can analyze the thermal images with IMAQ Vision image analysis functions. Figure 4 shows a thermal image of a printed circuit board (PCB). The yellow and red areas of the image represent hotspots on the board.

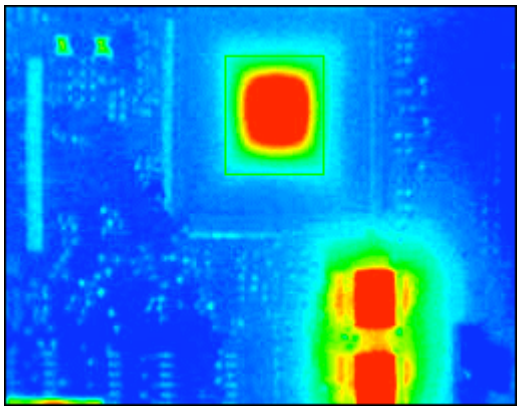

Figure 4. Using Thermal Imaging to Detect Hotspots on a PCB

Choosing the Right Camera

The following table compares different types of cameras.

Table 1.

	Analog Cameras	Parallel Digital Cameras	Camera Link Cameras	IEEE-1394 Cameras
Data Rate	Slow	Fast	Fast	Slow
Spatial Resolution	Low	High	High	Medium
Functionality	Simple and easy	Advanced	Advanced	Simple and easy
Pixel Depth	8-bit to 10-bit	Up to 16-bit	Up to 16-bit	Typically 8-bit
Cabling	Simple BNC cabling	Thicker, custom cabling	Simple, standard cabling	Simple, standard cabling

Camera Advisor

Camera Advisor on ni.com/vision is a one-stop Web resource for engineers and scientists who need to select a camera for their imaging application. Using this catalog of cameras, you can compare features and specifications for more than 100 cameras. Camera Advisor also explains how various cameras work with National Instruments hardware and software.

Image Acquisition Hardware

You should consider the following hardware features for your machine vision or scientific imaging applications: onboard memory, fast data transfer to PC memory, advanced triggering, integration with data acquisition and motion control hardware, and preprocessing functions.

National Instruments high-speed image acquisition (IMAQ) devices provide up to 80 MB of onboard memory. With onboard memory, you can acquire at extremely high rates while sustaining high-speed throughput and greater overall system performance.

NI uses state-of-the-art digital technology to maximize throughput over the PCI bus. This technology allows you to acquire images from high-speed digital cameras with low latency and no loss of data.

National Instruments line of IMAQ devices includes boards that connect to parallel digital, analog, and Camera Link cameras. These devices include advanced triggering and digital I/O features that you can use to trigger an acquisition based on a digital signal from photocells or proximity switches. You can also use digital I/O signals to strobe lights or relay devices.

Most IMAQ devices work with motion control and data acquisition hardware using the real-time system integration (RTSI) bus. On National Instruments PCI boards, the RTSI bus connector sits on the top of the board. You can use a ribbon cable to connect RTSI connectors on adjacent boards and send triggering and timing information from one board to another. On National Instruments PXI boards, a PXI Trigger Bus on the PXI backplane replaces the RTSI.

IMAQ devices support preprocessing, which can improve the performance of your application. IMAQ devices can perform such tasks as pixel and line scaling (decimation) and region-of-interest acquisition.

Low-Cost Standard Monochrome Boards

The PCI-1407/PXI-1407 Series boards offer low-cost, single-channel, monochrome, analog acquisition. You can configure the IMAQ PCI/PXI-1407 for standard RS-170, CCIR, and progressive scan analog monochrome cameras. The 1407 Series offers advanced features, such as partial image acquisition, onboard decimation, lookup table processing, programmable gain, and triggering.

Standard and Nonstandard Multichannel Board

The PCI-1409 board offers easy-to-use driver and camera configuration software for up to four standard and nonstandard analog cameras. You can use the PCI-1409 to acquire images from nonstandard cameras that have variable pixel clocks from 5 MHz to 40 MHz. You can configure a monochrome acquisition from RS-170, CCIR, NTSC, PAL, RGB, and progressive scan cameras.

Low-Cost Standard Color Board

The PCI-1411/PXI-1411 boards are configurable for color image acquisition from standard NTSC, PAL, and S-Video cameras. You can also acquire from monochrome RS-170 and CCIR cameras. The 1411 Series offers fast onboard color conversion to Hue, Saturation, and Luminance (HSL) image data before transfer to PC memory. This feature is especially useful during high-speed color matching and inspection applications, particularly in environments with varying illumination.

National Instruments Digital Boards

Digital cameras offer high-speed image output. Some digital cameras can output data at a rate greater than 100 MBytes/s. The IMAQ 1424, 1428, and 1422 Series digital image acquisition boards work with digital cameras from many manufacturers. The boards are ideal for fast, large images and high resolution. With a digital camera IMAQ board, you can acquire images at thousands of frames/s with high grayscale and spatial resolution.

National Instruments' PCI-1424 device is one of the fastest digital image acquisition boards available, supporting up to a 50 MHz pixel clock and 32-bit wide digital input (four 8-bit pixels). With up to 80 MB of onboard memory, the PCI-1424 can acquire data at a top rate of 200 MB/s and can sustain 100 MB/s. The PCI-1428 device helps remove the challenge of digital cabling by supporting Camera Link cameras. The PCI-1422/PXI-1422 boards feature a 16-bit input and support up to a 40 MHz pixel clock for lower cost, digital image acquisition applications.

National Instruments offers IMAQ hardware for digital cameras that have the low-voltage differential signaling (LVDS) interface. LVDS is a electrical standard that extends the performance of the commonly used digital camera RS-422 differential data bus. RS-422 limits the frequency to the 20 MHz range. However, LVDS cameras can clock data out at 50 MHz using the IMAQ PCI-1424 LVDS board. And, you can use the LVDS of the IMAQ board to transmit data as far as 100 ft. LVDS also reduces noise significantly.

Driver Software

Whether you are using LabVIEW, Measurement Studio, Visual Basic, or Microsoft Visual C++, the NI-IMAQ driver software gives you control of National Instruments image acquisition devices. NI-IMAQ is a complete, robust API for image acquisition. It performs all the computer and board-specific tasks for straightforward image acquisition without register-level programming. NI-IMAQ is included with the purchase of any IMAQ device at no charge.

Figure 5 shows how easy it is to use NI-IMAQ with the IMAQ Vision for LabVIEW image processing library. With only three icons in LabVIEW, you can snap and display an image. You can easily build more complex configurations using this LabVIEW diagram as a foundation.

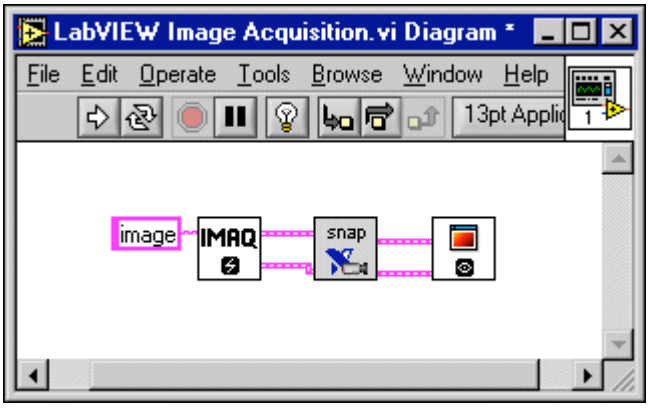

Figure 5. A Simple LabVIEW Diagram that Acquires and Displays an Image

The following is the IMAQ Vision for LabWindows/CVI code that performs the same snap as the diagram in Figure 5.

```
// This sample demonstrates how to acquire a picture using a high level snap operation
#include "stdafx.h"
#include <windows.h>
#include "snap.h"
#define _NIWIN
#include "niimaq.h"

int main(int argc, char* argv[])
{
// Window Handle of the display window
static HWND ImaqSmplHwnd;
```

```
// Imaq globals
static SESSION_ID Sid = 0;
static INTERFACE_ID Iid = 0;
static Int8* ImaqBuffer=NULL;

// Create a window to display the image
ImaqSmplHwnd = CreateIMAQWindow();

// Open an interface and a session
imgInterfaceOpen("img0", &Iid);
imgSessionOpen(Iid, &Sid);

// Snap a picture
ImaqBuffer = NULL;
imgSnap(Sid, (void **)&ImaqBuffer);

// Display using NI-IMAQ
imgPlot((GUIHNDL)ImaqSmplHwnd, (void *)ImaqBuffer, 0, 0, 640, 480, 0, 0, IMGPLOT_MONO_8);

// Close the interface and the session
imgClose(Sid, TRUE);
imgClose(Iid, TRUE);

return 0;
}
```

Lastly, the following is the IMAQ Vision for Visual Basic code that performs the same snap operation as the above code and the diagram in Figure 5.

```
Private Sub Snap_Click()
'Get the interface name and load the parameters set in
'Measurement & Automation Explorer (MAX)
CWIMAQ1.Interface = IntfName.Text
CWIMAQ1.LoadInterfaceDefaults

'Acquire asynchronously one buffer
CWIMAQ1.AcquireImage

'Display the most recently acquired picture in a Picture Box
'Note that it could be done more simply with the CWIMAQViewer object
'whose demo version is given, see the "Snap in CWIMAQViewer" sample
CWIMAQ1.WindowPlot Display.hWnd
End Sub

Private Sub Quit_Click()
End
End Sub
```

Once you write code to use with a particular image acquisition board or camera, you do not need to alter the code if you change to another IMAQ device. NI-IMAQ works identically across National Instruments entire product line of image acquisition devices and across a broad range of cameras.

NI-IMAQ is compatible with NI-DAQ and all other National Instruments driver software, making it easy to integrate imaging into any National Instruments solution.

NI-IMAQ is an extensive library of high-level and low-level functions that you can call from your application development environment. High-level functions include single-shot and continuous-mode image acquisition. Low-level functions include imaging sequence setup. Other functions include routines for video configuration, memory buffer allocation, trigger control, and board configuration. NI-IMAQ provides all the

functionality you need to acquire images and communicate with your camera. For image analysis and processing functionality, see the Analyze and Process Images section.

NI-IMAQ internally resolves many of the complex issues between the computer and IMAQ hardware, such as programming interrupts and DMA controllers. NI-IMAQ provides the interface path between the hardware product and LabVIEW, Measurement Studio, and other programming environments.

National Instruments Configuration Software

You can easily configure your image acquisition system with Measurement & Automation Explorer (MAX), which comes with NI-IMAQ. MAX is an interactive tool for configuring National Instruments hardware devices. You can use MAX to select the type of camera (RS-170, CCIR, NTSC, PAL, and nonstandard) you are using. You can also set parameters for the region of interest, black and white levels, antichrominance filter, asynchronous acquisition, gain, and exposure time. Additionally, you can use MAX to set up acquisitions from noninterlaced progressive scan cameras. You can also create your own camera configurations for nonstandard video by setting the VSYNC, HSYNC, and other timing information.

Scalability

NI-IMAQ driver software is designed to scale between many types of acquisition methods, as shown in Figure 6. This design consideration means that you can start using a low-cost, RS-170 camera and image acquisition board and upgrade later to a faster, higher-resolution camera and board with minimal software changes. To start using a new camera or board, all you need to do is configure the new hardware in MAX, the configuration utility for NI devices. Because NI-IMAQ uses one set of function calls that work for a wide variety of cameras, you do not need to rewrite your software.

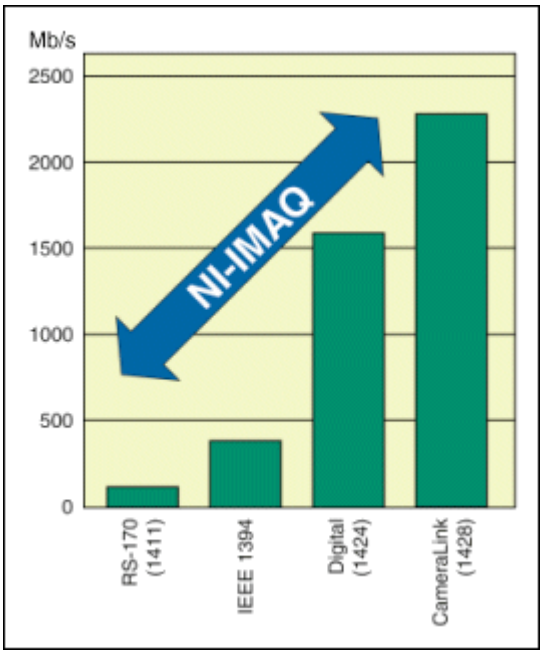

Figure 6. NI-IMAQ Allows You to Interchange Cameras without Rewriting Your Application