QUALITY VISION INTERNATIONAL INC.

Digital Cameras

This paper outlines some general principles of video metrology cameras. Today, there are many more choices of video cameras and technologies available on the market, and with those many choices has come a bewildering amount of myth, legend and partial understanding about what makes a “good” metrology camera. In this paper, we hope to answer many frequently asked questions about video metrology cameras.

What Makes a Good Metrology Camera?

The first thing to understand in discussion of camera technology today is that not all video cameras are suitable for measurement. It is a common misconception that higher resolution (i.e. more megapixels) means a better camera than a lower resolution model. With so many high resolution cameras available at such low prices, it is easy to expect that a precision measurement system should routinely offer 8, 12 or even 14 megapixel resolution.

While this may be true for point and shoot pocket cameras and cell phone cameras, cameras intended for precision measurement rely on more important factors than raw pixel count for their quality. In fact, very high resolution cameras come with practical problems that make them less than ideal for measurement.

Like any component of a precision measuring system, metrology cameras must be stable through the range of conditions in which they will need to operate. Thermal stability – making consistent measurements over a range of operating temperatures – is one key characteristic. Not only must the camera remain stable through normal temperature variations, the camera itself must be cool operating so as not to add heat to the surrounding optical system. Many high resolution cameras generate significant heat when operating continuously at full frame rates – some becoming literally “too hot to handle” with bare hands.

Metrology cameras must also have highly symmetric pixels – pixels must be square and arranged orthogonally in the array with equal spacing between them. Arrays should have minimum opaque areas – deadwood between pixels that are not light sensitive – so that the greatest possible amount of array is available to image the part being measured.

The pixel size must be a good match with the magnification and resolution of the optics, and with the feature sizes to be measured. A high megapixel camera combined with poor quality off-the-shelf optics is far less capable than a sub-megapixel camera with good metrology characteristics.

Supporting electronics for metrology cameras must be of high quality. Cameras must have very high signal to noise (S/N) ratios to enable accurate measurement with real time image processing and must be highly linear - meaning that there must be a proportional change in output for each corresponding change in light intensity in the image.

Cameras must also have a wide dynamic range – the ability to detect subtle intensity changes in scenes that are either quite dark or brightly illuminated.

And of course, metrology cameras – and their manufacturers - must have high quality and reliability over the long haul.

At QVI, these and many other factors are evaluated when we qualify any video camera for use in one of our products.

From the earliest days of QVI video systems in the early 1980’s we have qualified only seven (7) different cameras for use in production video systems. On average, it takes two years of R&D and one year of pre-production prototype testing to completely qualify a camera before it enters widespread distribution.

Analog vs. Digital – Which is better?

The terms Analog and Digital can be quite confusing when it comes to metrology cameras. Most "analog" cameras used for measurement today are mostly digital, and most digital cameras are at least partially analog. So how do we make sense of it all?

All video cameras use a sensor comprised of pixels – individual light sensors – that output a minute electrical signal which is proportional to the amount of light they sense. This is inherently an analog process – with the conversion to "digital" happening as the electrical impulses from each pixel are processed by the camera's electronics.

Most analog cameras rely on a "frame grabber" circuit board that captures, stores and digitizes the pixel data from each snapshot. Typically, the frame grabber converts the digital image back to analog form to display it on the system monitor.

Digital cameras have their A-D conversion electronics on-board, and plug directly into the PC where the pixel data for each frame is processed (digitally) by the camera's driver software. These two techniques provide the same basic data to the measurement software, but they do it in slightly different ways. The question we are left with is what makes digital better?

First, digital cameras eliminate the need for a dedicated interface (frame grabber) board in the system computer. This means lower cost, better reliability, and in the long run, greater flexibility for the user, since the computer can be upgraded to a newer model more easily than one which must operate a particular circuit board.

Second, digital cameras use advanced electronics that enable faster and more intelligent processing of the pixel data. The advantages here are small for traditional VGA or CCIR format cameras with about 300,000 pixels, but as the camera resolution increases to 1.0, 1.5, 2.0, or even 5.0 million pixels, the advantages become clear. Trying to process one million or more pixels using a traditional analog frame grabber with an A-D conversion and a subsequent D-A conversion for the display would simply take too long. Real time imaging would not be practical during measurement.

Third, digital cameras enable on-the-fly image enlarging, also known as digital zooming. Digital zooming is actually a change in the ratio relationship of camera pixels to video monitor pixels. As the "digital zoom" level is increased, the number of monitor pixels used to display each camera pixel is increased. In other words, the image appears bigger on the screen.

Digital zooming does not increase the optical magnification of the image presented to the camera, and thus does not improve measurement accuracy or resolution. What it does do is make it easier to observe the image, and place video measurement tools exactly where you want to measure, which does indeed improve measurement performance. An enlarged image is very useful for inspection purposes – finding defects, for instance – and for visual record keeping.

Keep in mind that field of view size – the area that can be viewed in a single image – is reduced as the optical magnification goes up. The trick is to balance the magnification need to measure accurately with the convenience of being able to see and simultaneously measure a larger area.

With a high resolution digital camera, it is practical to measure accurately at a lower optical magnification than would be possible with a traditional "low resolution" analog camera. At lower mag, we can measure more quickly, and program set-up is faster too, provided we can enlarge small features in order to place edge finders at the right locations. Digital zoom enables this, and thus offers a potentially huge improvement in throughput by allowing accurate measurement at a lower magnification.

Taking good advantage of high resolution cameras with digital zooming requires good optical resolution – by good, we mean resolution that is a good match with the pixel size of the camera. A good match is one that typically has at least 7-10 pixels "in transition" where an edge occurs in the image. Of all the megapixels in the camera, it is these handful of pixels in transition that are used to make measurements. Consider this example:

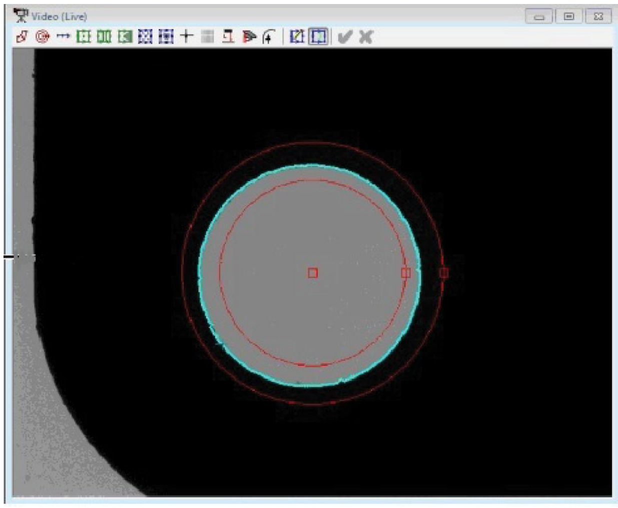

Figure 1: Video Measurement of a Thru-Hole

As the camera reads out pixels from left to right in this image, the intensity curve would look something like this:

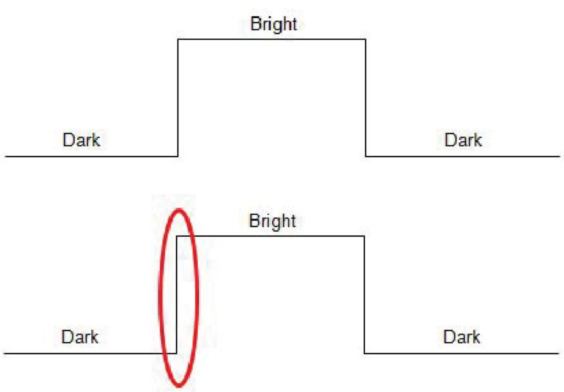

Figure 2: Intensity Profile of a Thru-Hole

The areas of interest where we want to make a measurement are on the transition from dark to light, as shown in the red circle. If we look closely at a plot of pixel intensity in this transition area, we would see something like this:

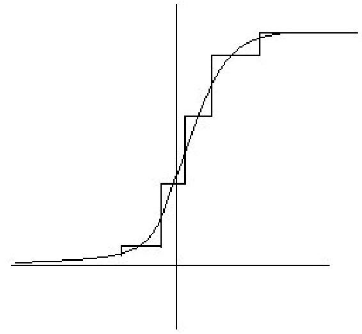

Figure 3: Convolved Intensity Profile

The transition from dark to light actually spans several pixels. Analyzing the rate of change between adjacent pixels is a more precise means of determining the edge location than binary processing because it ultimately allows sub-pixel resolution of each measurement.

If the image is so sharp, or the pixels so large, that the transition occurs in just one or two pixels, the image processing software has very little data to work with, and the measurement will not be as accurate or repeatable as it could be.

Conversely, if the imaging optics have poor resolution, the part image may not be accurate, and even a high resolution camera will not make an accurate measurement.

Since industrial metrology covers a broad range of parts, feature sizes and tolerances, we offer several different optical system and camera combinations.

For applications where the feature sizes are large (millimeters), moderate magnification levels are required, and we can enjoy the convenience and flexibility of a zoom optical system. For this type of application, an ultra- high resolution camera is not needed; a camera with nominal pixel size of 6-8 microns provides good performance.

For micro fabricated parts with feature sizes in the 1- 50 micron range, a fixed lens, optical system with a 20X to 100X, High N.A. objective lens is typically used. This arrangement will present a sharply focused, high resolution image, and will benefit from a high resolution megapixel camera with a pixel size of around 2 microns.

In between these two extremes, we use a variety of high resolution zoom and fixed lens optical systems that work well with medium and high resolution cameras.

The key is matching the camera's pixel size and resolution to the optics, and to the measurement at hand.

The Future of Digital

The benefits of moving to all digital cameras are numerous – offering better measurement capabilities, high reliability and lower costs.

A well qualified digital metrology camera will enable faster measurement with better resolution and accuracy than the same system with a traditional analog camera.

More pixels will provide improved resolution provided the optical system and camera pixel size are a good match with the parts and features to be measured.

Digital cameras offer lower cost and greater reliability. There is no video card; therefore a more compact computer can be used. Connections are simple, and include fewer components that could fail.

Digital zoom allows convenient program set up, while enabling programs to run at a lower magnification – with larger field of view – than would be possible with an ordinary analog camera.

Digital images are easily stored, allowing images to be saved for reference, or even re-measurement off line should the need arise.

New StarLite and Sprint MVP systems with digital cameras can be set up to have the same magnification range and field of view as existing SmartScope MVP and Sprint/CNC systems with analog cameras. Existing Measure-X routines are compatible between such systems.

Please visit www.qvii.com or one of the QVI division websites for more information.