Taking advantage of Low Distortion Large FOV (field of view) Vision CMMs

Many CMM programmers also get involved in optical inspection applications. For metrology applications, most vision systems employ magnification of the image to improve measurement accuracy and repeatability. The image is captured on an XY grid of pixels, and this optical grid replaces a touch probe, with the advantage of capturing thousands of points simultaneously. For some applications these systems employ very high magnification to image and measure features that are far too small to measure with contact measuring devices. These high magnification systems tend to have a very shallow depth of focus, in fact many of the higher-end systems even use focus as a technique to gather dimensional measurements in the “Z” axis of the measurement volume.

In the metrology lab, the standard thinking is that higher resolution is better, it usually improves both the accuracy and repeatability of the measuring device. Higher resolution can even enhance the ability to perform a 3D error map of a CMM - if the errors a machine produces are not repeatable, the error map is compromised. Following this logic, it seems that working at the highest magnification practical for a given application would be the way to go. As it turns out that is not always the case.

If you make parts similar to the ones below, a telecentric large FOV vision system may be helpful.

In the last few years large FOV (field of view) vision systems for dimensional inspection applications have captured an expanding segment of the vision metrology market. Given that a large FOV system works with lower magnification, which implies lower resolution, why would anyone use these systems? I admit to some initial skepticism about these new large FOV systems due to those resolution issues.

It turns out that there are a number of advantages to applying a large FOV vision system to many applications. One of the most significant benefits, is that these systems can measure a part contour much faster. The more of the part contour can be seen in one image the more of it can be measured without moving the machine stage to image on another area of the part. Image processing wins the speed battle easily. For some of the large FOV systems, processing speed is the primary advantage. Secondarily there is a clear ease of use advantage when the entire part contour can be measured in one image without having to program XY stage moves to measure the part. The limitation is these are strictly 2D measuring systems, focus cannot be used to take measurements in the Z axis.

Taking the case of the parts shown above, with a traditional vision system or even an optical comparator, when you set the focus on the top or bottom of the diameter, the outer diameter will be in focus, but the ends of the part and the vertical shoulders of the various diameters will not be in focus, as they are in a different focal plane. So if you need to measure distances of those vertical walls to some other feature, the walls can only be imaged using profile illumination (backlight) in a small area near the OD.
If you try to capture the edge by using surface reflection and focusing on the top of the part, now the process is much less reliable. Almost no edges are dead sharp (too dangerous to handle), so there is typically a slight corner break. So the inspector is relying on measuring the slim band of light where the edge breaks into the shoulder, hoping to get a good image on that edge. That type of illumination is very sensitive to variation in the condition of the part edge. This is especially problematic when an automated inspection sequence needs to be reliable. The inspection program may run great on one run of parts, then for another run of parts there is a some slight variation in the edge condition, causing the inspection to abort, or even worse, returning incorrect results. Bottom line is that profile illumination is more reliable for finding edges for most applications.

That edge image problem could go away if the entire contour is in focus, and generally the lower the magnification, the better depth of focus there will be. This is a natural advantage of a large FOV system, it works at lower magnification, with the accompanying greater depth of focus.

The depth of focus for an optical system can be enhanced further with the use of telecentric optics. Telecentric optics provide an orthographic projection, giving an object the same magnification at all distances from the sensor, and also turning a 3D image into a flat 2D image. Below is a graphic comparing telecentric vs non-telecentric images:

For the human eyeballs, we need non-telecentric optics. The non-parallel light rays are what tell you that the bus is about to hit you, as the closer it is the larger it appears. But if you are trying to accurately measure a part contour where distance of the contour varies relative to the lens, the last thing you want is for the size of the image to shrink or grow relative to the distance from the lens.
The main concept for a telecentric optical system, is to reduce the non-parallel light rays with a reduced aperture at the focal point of the lens (like using a higher F-stop on a camera when talking a picture for greater depth of field). But a really good telecentric optical system also requires a much more sophisticated lens shape to optimize the depth of focus while maintaining low distortion of the image. For a large FOV optical train, the lens will also be a much larger piece of precision ground glass. So these lenses will typically cost several thousand dollars more than a standard lens, as that large special lens is expensive to make.

QVI (Quality Vision International) now offers large FOV measuring systems on several platforms. The Ram Snap looks a lot like a traditional vision CMM with a vertical optical train, and a glass stage. They also put those same optics in an optical comparator body, which they call the C-Vision. That system is part of the CCP (Certified Comparator Products) line. In the case of the QVI large FOV optics, they specifically offer telecentric low distortion optics that insure the dimensional accuracy of the image to be measured.

Over the last month we (Visual Precision Inc.) have been doing a bunch of application work for several customers, and as part of the project development we have done direct comparisons between measurements with traditional vision systems with higher magnification optics, and the measured results from the large FOV systems. The following conclusion will sound really obvious in hindsight: it is way easier to measure a part when the entire profile is in focus. For the telecentric image the focus was centered on the OD, yet the entire contour is in focus. Using a standard optical system, when focused on the OD, the rest of the contour is not in focus. Here are a couple comparison images:

The above images clarify this discussion. If you need to measure the entire contour, the telecentric optics provide a crisp image, while the non-telecentric image has blurred edges on the vertical shoulders. So what about the loss of resolution due to working at lower magnification? Well the telecentric image gains some back - image processing software in a vision system makes finds an edge by making a decision about where the center of the edge is on the pixels. If you were to magnify an image up on the pixel array, most all edges become kind of blurred, and the edge is a curve, a transition from dark to light. So the software calculates the center of that curve. Well if the edge starts with a sharper crisp image, the curve from dark to light is steeper, so the edge calculation is more repeatable. So you give up some magnification, but you have sharper edge features to work with from the telecentric optics.
Not all large FOV vision systems are truly telecentric. Actually that is the specific advantage of the QVI Snap style optics. When QVI tests their large FOV optics for distortion they use a pretty simple technique: they use a calibrated sphere, similar to the qualification sphere on your CMM. They place the sphere in the field of view, and measure it at different distances from the lens, and also in various positions in the field of view, to quantify the optical distortion.

So if you are looking for a large FOV system (or already own one), and you want to run a test for optical distortion just use a precision sphere and make comparison measurements at different distances from the lens, and at different positions in the big field of view. Don’t take anybody’s word for it when you can easily test for it.

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