2-D Vision for a 3-D World

by Gary Hobart

Precision inspection enables manufacturers to produce nearly perfect parts

The coordinate measuring machine (CMM) business continues to churn out emerging technologies at an eager pace. Likewise, the 2-D vision measurement industry also is moving with the times. As modern day manufacturing increasingly relies on 3-D computer-aided design (CAD) data to produce accurate parts, the vision world has made the leap into this new dimension.

Vision measurement entered the 2.5-D arena when auto-focus routines allowed a camera and depth of field of the lens to report a third dimension. This was a major milestone for the vision industry as height measurement and two-dimensional metrology could be processed automatically from a DCC machine. Three-dimensional measurement via algorithmic processing of point data soon emerged into the focused measurement arena but was somewhat of a compromise with pure vision metrology. This circumstance was due to XY data always being more calculable than the elusive Z dimension, which was a variable as a result of magnification and depth of field of the lens used on each system.

Multisensor technology presented an interesting turn of events for vision metrology systems. By coupling a vision system with a laser or a touch probe, a new level of measurement accuracy emerged on the scene. This new media for vision was still not as simple as “bolting” a probe to the machine and having the system operate as expected.

Cross-probe calibration of the primary video sensor proved to be a great challenge. Measuring the same feature with both or all probes proved difficult for some and virtually impossible for others. This problem was mainly due to eliminating the natural inaccuracy that is inherent in zoom cells for all axes, and matching that value to the center of the probe tip or the laser spot. With sophisticated calibration techniques, those hurdles were solved.

What is a 3-D Vision System?

Every optical measurement device ever created is trying to reproduce the ultimate image processor—the human eye. Vision software coupled with a CAD model and a vision measurement system is the closest replica of the human eye to date. *Source: Hexagon Metrology*

Today's 3-D vision machine primarily uses vision-based inspection and can be equipped with a variety of additional fully functional probes—touch, laser, or white light sensors (WLS)—which earns it the multisensor designation. The system is constructed from a series of "building block" components, that when combined, will solve the customer's individual measurement needs or applications.

Each sensor—touch, laser, WLS—can serve many purposes, but the vision probe is fastest and most accurate for 2-D measurement in the planular field, or XY predominantly. Although capable of Z measurement, the vision sensor's accuracy is impeded by the depth of field of the lens without assistance, and therefore, its accuracy is governed by magnification.

Let's explore each sensor:

- Touch probe. The touch probe's accuracy is related to the length of the styli and styli diameter used. Accuracy can be improved by using a motorized probe head instead of the star-like styli and orientating the probe head to the normalized vector of the feature being probed.

- Laser. Lasers fall into many categories and break down into two types: triangulation or through the lens (TTL). Both have several advantages and disadvantages. The triangulation type has a fixed working distance and spot size, and is normally high in range. The drawback is the reflection of the transmitted light (laser) to the receiver is needed so there is a limitation to the angle of measurement.

- TTL lasers are less restricted as the transmission and reception of the laser is through the same lens. This means the operator needs to be much closer to the image for measurement, and the depth of field of the lens influences accuracy.

- White light sensor. The white light sensor is like a TTL laser, and in itself is a TTL sensor. Unlike lasers, WLS in not concerned about the amplitude or signal strength of the return signal; it just measures light in excess of 26,000 color levels. A single color is chosen and checked for the return value. The amplitude or power is not influenced, and extreme angles can be measured in excess of 88 degrees to the probe.

Accuracy Reaches Submicron Level

Vision system accuracy is dependent on the sensor being used and the item being measured. Rules of thumb for a vision probe are the resolution is 1/ of a pixel, and measurement capabilities are in the order of of a pixel. With the WLS and the shortest wand length—the term used to describe the probe of the WLS—the resolution can be nanometrology capable—far higher than the machine's mechanical movement capability.

Without mincing words, this means the smallest object a vision system could measure would be the equivalent of one-third of a pixel. Using very high magnification, this measurement would be in the submicron level for a vision probe. When used in tandem with a white light scanner, it could be as low as nano technology. On the opposite end of the spectrum, the largest vision systems might have a 1.5 x 1.6 meter bed with a 400-millimeter Z capability to accommodate large, but relatively flat objects.

A few examples of industries and applications that benefit from the vision system's submicron measurement capability are watch manufacturing; small machined parts such as gears, shafts, pins, dials; semiconductors and circuit boards; small ceramic or stamped parts; medical components such as bone screws, knee and hip joint replacement parts, bone plates, blood gas analyzers, micro closures, connectors, miniature moving parts for devices such as pumps or valves, precision molded or machined parts.

CAD Makes Its Mark

A critical turning point for the metrology industry was the introduction of CAD-based inspection. Manufacturers can now use their CMMs for 3-D data acquisition, but also can use a 3-D CAD-designed model itself as the inspection medium. By leveraging precise CAD models, design and mechanical engineers now have the perfect master—the true digital artifact that could be used for manufacturing following the Zero Defect principles of the day. Solid modeling has introduced a new era of visualization. A mechanical part or component could now be designed and viewed just as it would look when it was manufactured in 3-D—perfect in size and shape in every way.

Source: Hexagon Metrology

In the beginning, vision metrology manufacturers struggled with the 3-D CAD world concept, as probing meant what could be seen could be measured. Two changes occurred. First, the strategic rotation of a component could be implemented during the inspection process. And secondly, the rotation of a probe coupled with a CMM was the catalyst for 3-D optical video metrology for the manufacturer using CAD technology as it was meant to be used.

Vision Software Breaks 3-D Ice

Vision system accuracy is dependent on the sensor being used and the item being measured. Rules of thumb for a vision probe are the resolution is 1/10 of a pixel, and measurement capabilities are in the order of 1/3 of a pixel. *Source: Hexagon Metrology*

Every industry, both large and small, either generates or handles 3-D CAD in their daily production processes from their machine tools right on down to their inspection room. From design to shipment, a paperless digital operation is the goal for each component manufactured based on accurate CAD data.

Vision software has built the bridge from 3-D CAD to 3-D inspection. By simply clicking on geometry acquired for inspection, the data is aligned to the CAD model using a multitude of options from simple prismatic alignments to complex iterative continual adjustments of a best-fit method. The optimum performance of the machine and model are matched as measurement progresses. Point and program measurement is as simple as the steps it takes to complete the job:

1. Select the geometry.
2. Select the form.
3. Select the feature.
4. Process the data to geometric dimensioning and tolerancing for true 3-D measurements to CAD.

Why is this so important? Precision inspection enables manufacturers to produce nearly perfect parts, and industries such as medical part manufacturing depend on this capability. Organic forms such as artificial joints are being manufactured based on very complex forms, parabolas and surfaces that require advanced inspection techniques. Our quality of life depends on manufacturers ensuring the best possible inspection is carried out on mission critical parts.

Every optical measurement device ever created is trying to reproduce the ultimate image processor—the human eye. Without thought, the eye can discern color, shape, size, form and depth in an instant, and our brain instantly and seamlessly processes this data automatically. In the very same way, vision software coupled with a CAD model and a vision measurement system is the closest replica of the human eye to date.

Sky's the Limit for Vision

Too many times, a customer feels forced down an inspection machine path because the sensor technology they need is only available on certain types of systems or machine sizes. Vision systems today offer the building blocks of life.

After the maximum component size for a measurement application has been determined, the customer has a utopian world of add-on options. They can enhance their system with nearly every form of sensor or movement technology from rotational (single or dual) axis measurement to a dual Z capability. As a company's budget or specifications change in the future, the vision system offers long-term scalability and a continued return on investment.

The vision industry has come full circle into a 3-D world. The advances in dual Z-axis technology, inspection software and CAD-enabled verification culminate in a 3-D solution that a veteran vision operator would believe impossible from a 2-D video world-view. Three-dimensional vision has newfound metrology rewards to empower manufacturing and those who strive for the flawless product. **Q**

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For more articles on vision measurement, visit www.qualitymag.com for these articles:

- *"Machine Vision Goes Beyond Sight,"* by Larry Adams
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- Case Study: *"Vision Inspection Ensures Current Quality"*

Tech Tips

Today's 3-D vision machine primarily uses vision-based inspection and can be equipped with a variety of fully functional probes.

- Vision system accuracy is dependent on the sensor being used and the item being measured.

- Manufacturers can now use their CMMs for 3-D data acquisition as well as use a 3-D CAD-designed model itself as the inspection medium.

- Vision software coupled with a CAD model and a vision measurement system is the closest replica of the human eye to date.

Understanding Vision Accuracy

Unlike tactile probing metrology methodology, vision measurement accuracy is a constantly changing variable. There are three main influencing factors governing the accuracy of vision measurement: lighting, magnification and edge quality.

Lighting. Without being able to see the component or an edge, the image processing will fail. However, too much light also is bad. By flooding an image with light, the edge location will move and change the actual size of the measured component. The balance of light is critical in any video measurement application.

Magnification. By increasing magnification, the field of view resolution is increased, effectively improving the accuracy of each measurement. However, there is a point where too high a magnification distorts the measurement as a result of component quality. The opposite is true; if magnification is decreased, the field-of-view resolution is decreased. Thus, the resolution might be insufficient to measure the component at the required accuracy. The pixel size and measurement tolerance must be observed prior to setting magnification or attempting measurement.

Edge quality. Edge quality depends on the material. For example, a piece of paper will look sharp and clean when first looking at it, but when the paper is magnified, fibers appear on the paper. Now, tear the paper and look again. This time the fibers are visible with the naked eye. This is edge quality.

By combining and understanding lighting, as well as magnification and edge quality, the repeatability and accuracy of the vision measurement can be improved. By following the rules, more reliable programs can be created and more consistent and reliable measurement results can be achieved. Be prepared to edit the part program as a matter of course and maximize the tools available from the video measurement software.

History of Vision

In order to understand the 2-D to 3-D transition, first look at the fundamentals of vision science. Vision measurement has been around since 100 A.D. when the Romans realized that viewing objects through a shaped piece of glass made them appear larger. Microscopes were introduced in 1600 and were transformed into a measurement device because smaller objects were easier to measure when viewed at a larger size. Modern medicine, engineering and education all benefited greatly from this invention. Where would the world be if Louis Pasteur had been without a microscope?

The next significant innovation was the profile projector, also known as an optical comparator, which gained large-scale industrial usage in the 1950s. This system places an image in silhouette and projects the image via a mirror, or series of mirrors, onto a ground glass screen. Measurement overlays of the perfect component are drawn and “optical comparison” was born. Thousands of these devices are manufactured and used today for comparison, and in some cases link to a microprocessor for geometrical measurement, or automated for two-dimensional inspection on a large-screen format.

Moving to the 1970s, these two processes intersected when a profile projector and measuring microscope were merged using camera-based technology for video measurement. This breakthrough served multiple industries by providing binary, or black and white, video inspection of profile components automatically in a DCC format.

In the 1980s, the development of gray-scale image processing was a large leap forward for measurement. Surface lit information could be processed, thus making 2-D measurement a reality for all components. And secondly, the microscope portion of the system could use the camera, processing power from the computer and software to interpret edge location for basic geometry. By the mid 1980s, a high-speed scanning system was developed which profiled cylindrical components in a single scan, and this vision technology is still used successfully by manufacturers today

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