Using Machine Vision for Precision Gauging

Human vision is capable and flexible but can't make fast, precise and repetitive measurements. In these cases, a machine vision system is your best choice for precision measurements. Quality Magazine has many articles on the basics of machine vision[1], so here we concentrate on how to use a machine vision system for precision optical gauging.

One of the best methods for precision optical gauging is to light the part being measured from behind using collimated light (parallel light rays, like a searchlight). This casts a sharp shadow of the part into a telecentric lens (a lens that accepts only parallel light rays) and forms an image on a high-resolution digital camera. Edge positions on the part are then measured to a fraction of a pixel using high-precision machine vision algorithms.

We will examine how this works in a real-life situation, and then will further explore the elements of a machine vision system necessary for precision gauging.

Precision Gauging in the Automotive Industry

Engineering Specialties, Inc. (North Branford, CT) manufactures millions of small, high-precision automotive parts. ESI custom builds machines to form and to inspect these parts for defects. An example is a machine that inspects pins used in a car seat-belt, where quality is extremely important. These pins are cut from a wire, the ends are chamfered, and a small, circumferential notch is formed with an Escomatic screw machine. The pin diameter is 60 mils (60/1000 of an inch), so these parts are small.

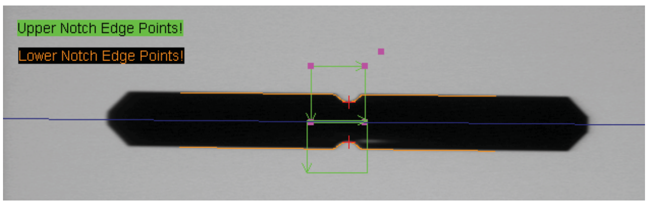

Figure 1. A pin part as seen "in flight" and measured by DALSA's Sherlock software.

Formed pins are put in a feeder bowl, serialized, and dropped so that they fall between a collimated light source and a telecentric lens with a high-resolution DALSA camera. As they fall under the influence of gravity, a photosensor detects the part and tells a DALSA IPD Vision Appliance™ (a machine vision computer) to trigger image acquisition from the camera. The Vision Appliance runs DALSA IPD's Sherlock™ machine vision software to find the part and determine its angle in the image. The software then gauges the part at multiple diameters, including the circumferential notch.

[1]*For example, Troubleshooting Vision Systems (June 2008) or Machine Vision Makes Gauging Easy (September 2004)*

Parts that do not meet tolerances are blown sideways into a reject bin. Defects are recorded and presented as Pareto charts to help ESI improve the manufacturing process. Good parts fall into a bin and are shipped to ESI's customer. Parts are processed at the rate of two per second, primarily limited by the time required for the part to accelerate due to gravity and fall through the light-lens-camera sensor cell.

This inspection system runs 24 x 7 unattended. When the system needs more parts or servicing, it uses a wireless network to email and telephone an operator, even at the operator's home. The operator interacts with the machine using a custom Visual Basic interface built on "top" of the Sherlock machine vision software.

Carmen Ciardiello, VP and General Manger of ESI, admits that this seems like a lot of work for a little part. He says, however, "We built this machine because it makes economic sense given that we make 10,000,000 of these parts a year." He adds, "We are also risk averse so we want to make sure that zero defective parts go into seat belts."

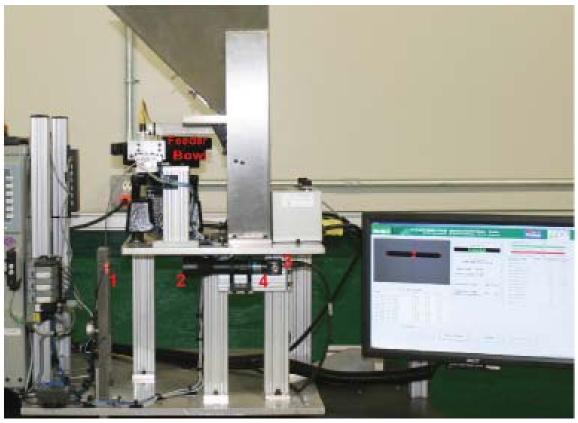

Figure 2. Formed pins in a feeder bowl, are serialized and dropped past a collimated light (1) and photosensor. A part image is taken through a telecentric lens (2) with a high-speed camera (3). The DALSA IPD Vision Appliance (4) processes the image to gauge the pin part. The operator interface is shown on the right.

Precision Gauging in Detail

Consider dimensioning strips of stamped metal parts, used for automotive electrical contacts. These parts are stamped and formed by a progressive punch press and inspected as they emerge from the press. Catastrophic failures – such as a die in the press breaking – are easy to detect. Detecting subtle changes in the part's dimensions, however, requires a carefully designed machine vision system. These subtle dimension changes warn that a die is wearing and so the parts are at risk of going out of tolerance.

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Collimated Light and Shadow Casting

A collimated, narrow-band light source illuminates the parts from behind and casts a shadow of the part that is imaged by a telecentric lens and high-resolution camera. The collimated light's rays are perpendicular to the part and so give very sharply defined part shadows. There is very little "bleed" of light around part edges so measured edge shadow positions are more stable as light intensity changes.

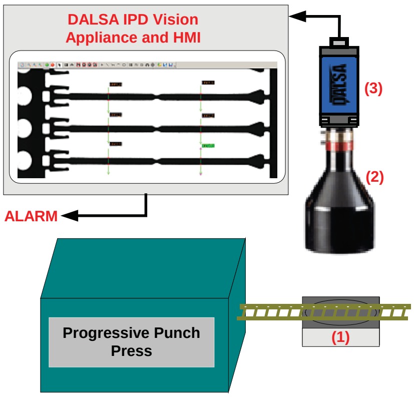

Figure 3. A progressive punch press stamps and forms a strip of metal into parts. Each part on the strip is inspected by a vision system that includes a collimated light source (1), a telecentric lens (2), a high-resolution camera (3), and a DALSA IPD Vision Appliance for edge extraction, human-machine interface (HMI) and reporting.

Shadow casting (parallel projection) using collimated light also reduces effects of part depth change on the imaged part dimensions. As the part moves towards and away from the camera, shadows cast by the part in the beam of collimated light do not change significantly in size.

A common type of collimated light has a point light source placed at the focal point of a magnifying lens, typically a Fresnel lens. A magnifying lens brings collimated rays of light to a focus point. This collimated light source is the reverse: a point light source at the focus goes "back" through a magnifying lens and becomes collimated.

Collimated light sources can also be made by running a telescope in reverse – light is input at the eyepiece and comes out of the objective lens in a collimated beam. Some vendor's use the phrase "telecentric light" for a collimated light, to indicate that the light rays are parallel to the optic axis and that the light source is to be used in combination with a telecentric lens.

Colored LEDs are commonly used as light sources for collimation. The LED's narrow bandwidth, about 25 nm, allows a sharp focus of the imaging (telecentric) lens without introducing self interference (speckle) effects seen in a coherent source such as a laser. As the LED wavelength decreases (towards the blue), measurement resolution increases slightly due to reduced effects of diffraction. This is usually only a concern when using a microscope to measure dimensions approaching the wavelength of light.

The Importance of a Telecentric Lens

A telecentric lens has a stop that blocks light rays that are not parallel to the lens' optical axis (the imaginary line from front to back at the center of the lens and perpendicular to the part being imaged). This complements the effects of collimated light by further reducing light "bleed" around part edges and further suppressing changes in imaged part size with shifts in part depth

A telecentric lens also has very little optical distortion so calibration and distortion correction are more precise. As only parallel light rays are accepted by the telecentric lens, the light from the collimated source is efficiently used and ambient light is rejected so part image contrast is high. However, the field of view of a telecentric lens is limited to the size of the lens's objective (the lens element facing the part). Microscope and other low-distortion lens designs are also used for precision measurement.

Sub-Pixel Measurements and Camera Resolution

To be very conservative, you want pixels on the camera's sensor to be no larger than twice the desired gauge resolution. In this example, the field of view is 1" x 1" and a 1600 x 1200 (width x height) pixel camera with 4.40 micron pixels was used. This gives a pixel size on the part of 0.625 mils, and half of that gives a sub-pixel resolution of about three ten-thousandths of an inch, as required by the customer.

How can we measure part edge positions to less than a pixel? As an edge moves across a pixel the measured pixel intensity changes, but not in any way that we could use to determine position, at least with the square pixels used in most machine vision cameras.

To make sub-pixel measurements we use the expected intensity profile across the edge being gauged. We assume that the edge intensity is a step that is blurred by the optics into an S-shaped curve so edge position information is "smeared" out into adjacent pixels. We can then recover the edge position within a pixel by looking for a peak in the first derivative of this intensity curve, or by other mathematical methods. This gives 1/4 to 1/25 sub-pixel resolution, depending upon the image and part edge quality. Finer sub-pixel resolution requires additional assumptions about the intensity structure of the edge and may not be appropriate when measuring parts whose edges change, in this example due to the stamping die wear. By designing the imaging system to require ½ pixel resolution, we are well within what sub-pixel computation can do.

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The camera, a DALSA Genie™, sends the image via Gigabit Ethernet to a DALSA IPD Vision Appliance – a computer with specialized hardware for image processing and control of the inspection system. The Vision Appliance uses DALSA's Sherlock software to gauge dimensions on each part and alert an operator when these dimensions are out of tolerance.

Summary

Precision gauging requires careful attention to each step of the process. It is best to start with a collimated back light to give sharp edge shadows and image the edges with a telecentric lens and high-resolution digital camera. Machine vision software with precise sub-pixel edge algorithms are then used to gauge part dimensions and to control the reporting and sorting of parts.

Glossary

Collimated light - light whose rays are nearly parallel, and therefore diverge slowly with distance. A perfectly collimated beam with no divergence cannot be created due to diffraction, but light can be approximately collimated by using lenses.

Fresnel lens - a type of lens invented by French physicist Augustin-Jean Fresnel. Originally developed for lighthouses, the design enables the construction of lenses of large aperture and short focal length without the weight and volume of material which would be required in conventional lens design.

Pareto charts – a bar graph with the bars sorted in descending order used to identify the largest opportunity for improvement; used to graphically summarize and display the relative importance of the differences between groups of data.

Sub-pixel resolution – position resolution that is smaller than the size of the individual sensor elements (pixels) of the camera, as projected back through the optics onto the part. Sub-pixel resolution can be obtained in digital images by using additional assumptions, such as the expected shape of the intensity curve across an edge, information that is not in the digital image itself.

Telecentric lens - a compound lens with the location of the entrance pupil and / or exit pupil at infinity. This means that only light rays parallel to the optical axis will pass through the internal aperture stop of the lens.

IPD Vision Appliance – DALSA's powerful and quick-to-deploy machine vision solution for automated quality inspection.

About the Author

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For more information on DALSA's machine vision systems, visit www.dalsa.com or call 978-670-2002.

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