TECH BRIEFS
ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

3D Machine Vision Using Laser Triangulation

Applications for 3D machine vision are rapidly expanding in a variety of industries for several reasons. The first is that vision systems can lower production costs by increasing yields and/or reducing scrap product and wasted raw material. One example of this would be extruded products from various materials (rubber, plastic, metal), where it's vital to know as soon as the process goes out of specification.

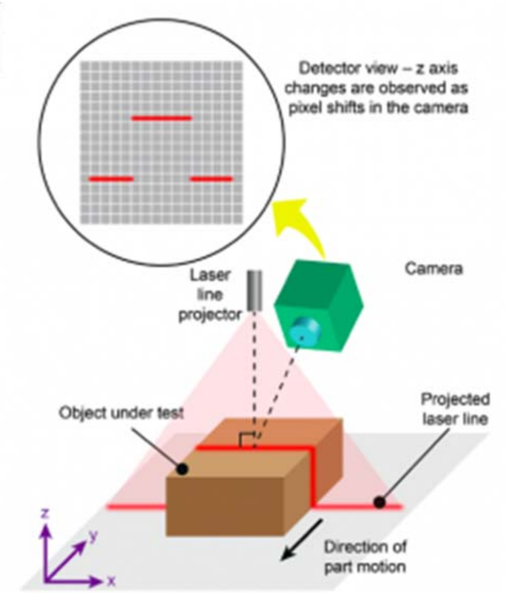

Figure 1. A projected laser line appears distorted when viewed from perspectives other than that of the projector. This distortion is calibrated and used to derive the dimensions of the object under test.

Another reason is improved product appearance or cosmetics. Here, for example, the alignment of joined parts in an assembly impacts the perceived quality of consumer products ranging in size from a smart phone case to the bodywork panels of a luxury automobile.

And of course, another important factor is improved functionality. An excellent example of this is the automotive tire industry, where components are extruded, molded and bonded in high volume. Process variations in any of these steps could limit the life of the tire, compromise handling, and could even represent a serious safety issue.

Advantages of Laser Triangulation

There are several non-contact methods for generating a 3D profile or image. A brute force method would be to use cameras from multiple viewing angles, and then assemble an overall surface contour image from these separate inputs. But often, only a limited number of very specific data points are required to monitor industrial processes, such as the separation of two body panels, or the parallelism of two or more cuts. Laser triangulation is a proven, relatively simple, and hence cost-effective way, to get this streamlined data. With clever use of structured laser light patterns, such as arrays of dots, straight lines, and grids, systems typically only require a single camera to simultaneously generate up to several pieces of critical dimensional measurement data.

Figure 2. An ALG combines the function of a prism and an aspheric cylinder lens.

The earliest, and still the most common, laser triangulation architecture is the single straight line projection geometry. Here, optics are used to form the laser spot into a straight line where it intersects the part under test. When viewed from other perspectives than that of the projector, this line appears distorted. Observing this distorted line shape with a camera then enables the system processor to compute a precise geometric reconstruction of the object's surface shape along the illuminated area.

There are several ways to implement this type of line-based machine vision and Figure 1 shows one of the most common, where the laser projection direction is at normal incidence to the surface of the part and the camera views at a non-normal angle. A variety of other configurations can be created, each of which has specific advantages in terms of resolution, absolute accuracy, and other metrology parameters. However, fundamental to any of these approaches is the need to create a laser line with the necessary uniformity, as defined by its straightness, intensity uniformity, and any width variations.

Line Generating Optics

The simplest way to generate a line profile from a laser beam with a Gaussian cross-section would be to expand the beam with a cylindrical lens. But this creates a line with a Gaussian intensity profile, and most applications require a line with reasonably uniform intensity along its usable length. Instead, there are four approaches in common use for transforming a Gaussian spot into a long line with a (more or less) uniform intensity profile. These are clipping the beam using an aperture, diffractive optical components, cylindrical lens arrays, and aspheric line generators (ALGs). The latter two are better suited to 3D triangulation applications for quantitative metrology and are the optics used in most Coherent laser/optics modules for this purpose.

The simplest method is to use an aperture in the beam to transmit only the central, most uniform portion, prior to expansion with a cylindrical lens. The main advantage of this method is its extreme simplicity and low cost. The biggest negative of beam clipping is that it reduces the available beam power, in some cases by up to 75%, and also generates diffractive edge effects from the aperture.

Diffractive beam homogenizers typically generate a line by transforming the laser spot into a repeating series of small, closely spaced dots. Depending on the specific technology used, this type of line suffers from various deficiencies. With high coherence lasers for example, this approach can produce interference fringes, which the imaging system interprets as scatter or noise, lowering measurement accuracy. And with passively cooled laser diodes, wavelength drifts cause changes to the

Cylinder lens arrays are a cost effective way to transform Gaussian beams into a more uniform intensity distribution with virtually no optical loss. Essentially, the method generates multiple small lines that overlap in the far field. This tends to produce patterns which have a substantial amount of high frequency ripple, and the ripple pattern varies with working distance. So this approach is not a good match where high resolution measurements in the xy plane are required.

A refractive ALG (Aspheric Line Generator) generates a uniform intensity profile by combining the function of a prism and an aspheric cylinder lens (Figure 2). The prism refracts the incoming beam into a spreading “fan” of light. The cylindrical aspheric lens redistributes the energy from the edges of the beam towards the center, producing a more uniform intensity profile. Since this is a refractive element, there is very little dependence on wavelength and virtually none on temperature. Plus the intensity distribution does not contain structure from interference or beam overlap effects. It is, however, important to closely match the incoming beam size to the dimensions of the optic. Any mismatch will affect resultant beam parameters. So, it is often best to use these in pre-aligned modules from an experienced laser beam shaping vendor.

The accompanying chart summarizes the main characteristics of each type of Gaussian beam transforming method.

	Clipped Gaussian	Diffractive Optic	Multi-Cylindrical Lens Array	Aspheric Line Generator
Parameters affecting line uniformity	Input beam position Input beam size	Wavelength Projection distance Detector pixel size	Projection distance Detector pixel size	Input beam position Input beam size
Side lobes along length of line	Diffraction caused by aperture	Higher diffraction orders	None	None
Applications	Bio-instrumentation Visual alignment	Visual alignment Scattering	Visual alignment 3D vision	Bio-instrumentation Visual Visual alignment Scattering 3D vision

Automotive Industry Applications

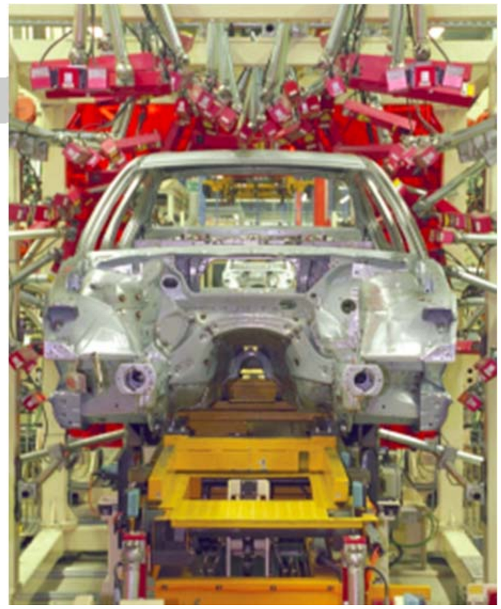

Figure 3. The contemporary automotive production line features an extremely high level of automation, including robotic actuators and supporting machine vision systems.

The mass production of automobiles and automotive components is becoming ever more automated, with smart robotic tools performing a wide range of tasks (Figure 3). To ensure consistent quality and specified performance, the robots are usually operated in a closed loop manner where laser triangulation is a common method to provide spatial feedback. Windscreen installation, tire manufacturing (and installation), side panel installation and alignment, and component-level inspection (clutch plates) are just some examples where laser triangulation plays a critical role.

Over 1 billion vehicle tires are produced worldwide annually. Each tire is built up on a drum from multiple components, starting with the inner liner (made of halobutyl rubber) which provides the air barrier needed to enable long, continuous (low-leak) inflation. Various fiber and rubber components are then successively added before the assembled tire is cured by a combination of heat and pressure. A key step is the application of the tread, called the “green tread” at this stage, which is made in a long continuous strip, and whose pattern and composition are optimized for long life, or sport handling, etc.

The green tread is made in an extrusion process that is monitored using a single laser line projection in the standard geometry described earlier. The line is projected at 90º to the extrusion direction, across the outer surface (i.e., tread side) of the continuously extruded strip so that the entire tread area is sequentially sampled. The vision system continuously measures the tread thickness and its detailed profile.

Key laser projector parameters for this application are line straightness, uniform line thickness, and high pointing stability. Good line brightness uniformity is also desirable, but not mission-critical. This application has traditionally been serviced with red lasers, but there is growing interest in blue and green wavelengths which will improve contrast, and possibly resolution.

Another long-established application at the component level is inspection of clutch plates for contour and dimensional accuracy, including height changes and surface irregularities. In this relatively simple application, a single line projection spans the diameter of the clutch plate as it is rotated. Triangulation of the line image then provides a high resolution scan of the entire plate.

As seen in Figure 3, laser triangulation is also widely used to provide 3D feedback in automobile body assembly – for example to check the orientation of body panels prior to welding and to correctly position the windscreen prior to bonding. Fenders, panels and doors are then all re-checked after assembly by laser triangulation. Consistent gaps are required for correct function, e.g., rain sealing, lower wind noise, as well as for cosmetic perceived value considerations. Here a line is projected across the gap between body panels or perpendicular to the edge of the windscreen. To increase speed of measurement by threefold, many of the body seam applications use three parallel line projections, rather than a single line for each of the four edges of the windscreen.

Summary

Laser triangulation is a flexible approach that is often the best solution to the growing need for 3D vision for process monitoring in numerous industries. While a laser line generator and camera is the simplest and most common implementation, the uniformity of the line is not a trivial consideration; it determines the quality of the data. This, in turn, strongly depends on the type of beam shaping optics used, which must be matched to the specifications and budget of the particular application.

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