3D Laser Scanning – Lasers and Machine Vision

Machine vision is an application space that integrates multiple technologies with the specific intent of enabling automated Quality Assurance. The use of lasers as illumination sources is a standard practice in achieving accurate, simple, and flexible representations of objects under inspection. Of particular use are the structured light laser products.

Understanding the benefit, use, and ultimate selection of structured lasers requires defining the theory behind extracting information from their use.

The core principle of use is triangulation. The use of this principle has particular interest in the identification and use of the height or position of a point or an object in arbitrary space.

Introduction
In geometry and trigonometry, the process of determining the location of an arbitrary point is called triangulation. Triangulation is accomplished by measuring angles to an arbitrary point from known points at either end of a fixed baseline, rather than measuring distances to the point directly. The point can then be fixed as the third point of a triangle with one known side and two known angles.

Distance to a Point by Measuring Two Fixed Angles
Triangulation can be used to calculate the coordinates and distance from the base AB to the point P. (See Diagram 1 below.)

The observer at A measures the angle α between base AB and the point P, and the observer at B does likewise for β .

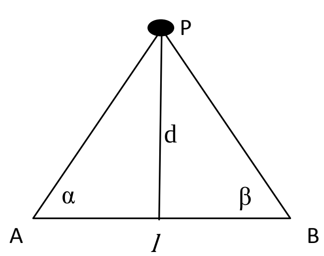

Diagram 1

With the length l or the coordinates of A and B known, then the law of sines can be applied to find the coordinates of the point at P and the distance d.

Calculation: The goal of the calculation is to identify distance d to any given point on the object with the known being defined by the user. To begin, we define the length (l) in the terms that we know, the distance between the two observation points, and the angles between these observation points and the given point on the object.

$$l = \frac{d}{\tan\alpha} + \frac{d}{\tan\beta}$$

Solving for d:

$$d = \frac{l}{\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right)}$$

Using the trigonometric identities tan α = sin α / cos α and sin(α + β) = sin α cos β + cos α sin β, this is equivalent to:

$$d = \frac{l \sin\alpha \sin\beta}{\sin(\alpha + \beta)}$$

From this equation, it is easy to determine the distance of the unknown point from either observation point, its offsets from the observation point, and finally its full coordinates.

Translation to Industrial Use.
Optical 3D measuring systems use the principle of triangulation to determine the spatial dimensions and the geometry of an item. Basically, the configuration consists of two sensors observing the item. One of the sensors is typically a digital camera device. The other sensor is a light projector.

The projection centers of the sensors and the considered point on the object's surface define a (spatial) triangle. Within this triangle, the distance between the sensors is the base AB and must be known. By determining the angles between the projection rays of the sensors and the basis, the intersection point – and thus the 3d coordinate – can be calculated from the triangular relations.

How are Lasers Used in this Process?
The fact that you can find a coordinate is good; putting this principle to work creates value.

What does putting this principle to work involve? It means deriving the information, establishing a coordinate system, and evaluating the "coordinates" of a given object against a requirement to establish if the object is good, bad, right, wrong, in or out of control, etc. calls for a specific mechanism.

Extracting value from this triangulation principle needs a physical system that provides "real-time" data from an object and facilitates decision making. In principle, knowing how to find a point is valuable, but slow. Building a coordinate map of a surface point-by-point is inefficient. Looking at slices or multiple slices provides a more efficient and accurate representation of the object under test. The accuracy of the coordinate map – and thus decisions made against it – are related to how thin a slice you can take. If the feature of the object is smaller than that of the line, the change in the coordinate cannot be seen. Thus the map of the object does not provide the information to make the appropriate decisions.

Projecting a narrow band of light onto a three-dimensionally shaped surface produces a line of illumination that appears distorted from perspectives other than that of the projector. These distorted perspectives can be used for an exact geometric reconstruction of the surface shape.

In a typical 3D triangulation sensor, the laser line provides two of the three dimensions of the object. The third is obtained by moving the object with respect to the sensor A faster method is the projection of patterns consisting of many lines at once, or of arbitrary fringes. This method allows for the acquisition of a multitude of samples simultaneously. Seen from different viewpoints, the pattern appears geometrically distorted due to the surface shape of the object.

Diagram 2 in the next column shows the geometrical deformation of a single stripe projected onto a simple

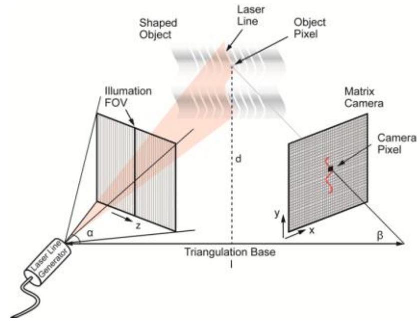

Diagram 2

3D surface. The displacement of the lines allows for an exact retrieval of the 3D coordinates of any details on the object's surface

Although many other variants of structured light projection are possible, patterns of single or multiple parallel lines are widely used. The non-uniformity of the stripe or line being presented to the object can affect the accuracy of measurement. As with the size of the slice, the return signal is interpreted as a change in the surface. A non-uniform line (in relative intensity) will have zones or areas that have significantly different return intensities off the object onto the camera. If these different return intensities are significant enough, this result can be viewed by the coordinate map as a gap or height change in the object.

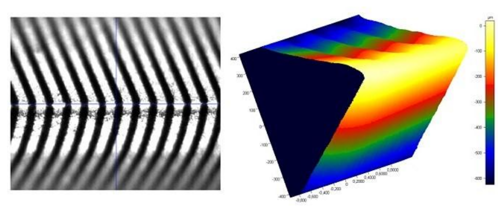

Diagram 3
False Color Height Map

Conclusion
The natural size of the longitudinal mode of lasers enables the thinnest slices, the highest power density, and best control over the projected light. The use of laser-based structured lights for 3D triangulation enables a simple and cost effective method to monitor, measure, and act on a manufacturing process, minimizing cost of quality and maximizing value of the end product to the customer.