TOC

The Basics of Triangulation Sensors

This tutorial explains the operating principles of diffuse and specular laser triangulation sensors, along with their advantages and drawbacks.

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Triangulation sensors fall into the general category of noncontact height or range measurement devices. A triangulation sensor may provide the same information as a linear variable differential transformer or contact probe, but without touching the object to be measured. The sensors work by projecting a beam of light onto the object of interest and calculating the distance from a reference point by determining where the reflected light falls on a detector (see Figure 1). As the point of light falling on the object moves closer to or farther from the reference point, the spot position on the detector changes.

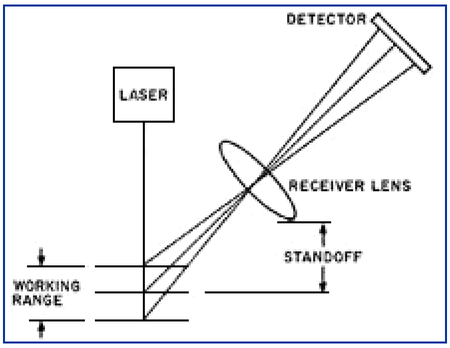


Figure 1. A diffuse triangulation sensor projects a beam of light onto a target and the reflected light is captured by a detector. Changes in the target height result in a corresponding change on the detector.

Sensor Types

Triangulation sensors are either diffuse or specular. The need for two types of sensors arises from differing reflectance characteristics of materials

being examined. Smooth surfaces, such as mirrors, are specular; others, such as anodized aluminum, are diffuse (see Figure 2). Smooth or shiny surfaces typically require a specular sensor (the laser illumination hits the target such that the primary reflected light is reflected into the receive optics), while surfaces that scatter light are easier to measure with a diffuse sensor. So the selection of sensor type is dictated by the surface of the object being examined. A measure of the received signal strength (more = better), or of the amount of time required to achieve a desired signal strength (less = better), is an indication that the right type of sensor has been chosen. Many surfaces, however, display both specular and diffuse

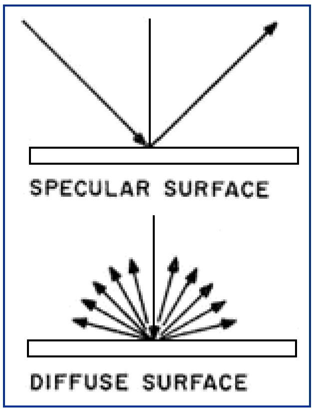


Figure 2. Specular surfaces are mirror like, producing a predictable reflection. Diffuse surfaces are irregular, resulting in scattered reflections.

characteristics and thus complicate the selection process. In those cases the user must experiment. (Often the sensor manufacturer will be happy to run an application study to help the end user decide which type of sensor is preferable.)

Sensor Subsystems

A triangulation sensor can be broken down into three subsystems: transmitter, receiver, and electronic processor (see Figure 3).

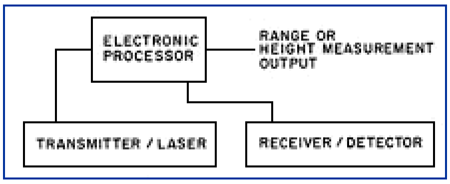


Figure 3. The electronic processor controls the transmitter that emits the laser beam. The beam illuminates the target object and reflects light into the receiver. The receiver transmits data back to the processor, which interprets the data and outputs a measurement.

Transmitter. The transmitter, typically a laser diode with beam-shaping optics, projects a beam that illuminates the target object. The most popular transmitter at present is an inexpensive, low-power 670 nm laser diode with a visible beam. The optics used to manipulate the laser diode output creates a small spot at the standoff distance. The size of the spot is dictated by the optical design, and influences the overall system design by setting a target feature size detection limit. For instance, if the spot diameter is 30 µm it will be difficult to resolve a lateral feature <30 µm.

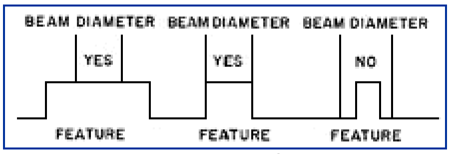
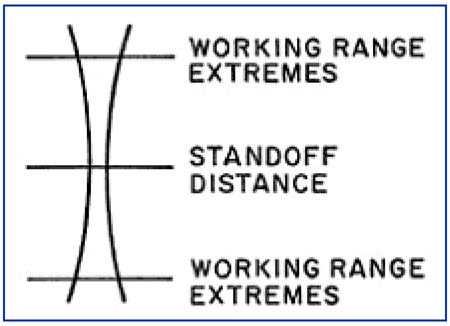


Figure 4. The diameter of the beam dictates the minimum measurable feature size, or spatial lateral resolution. To accurately measure a feature, the beam diameter must be smaller than or equal to the size of the feature.

Keep in mind that the feature size limitation is the spatial lateral resolution, approximately equal to the spot diameter (see Figure 4). Where the beam diameter is larger than or the same size as the feature, the sensor has sufficient resolution; where the feature is smaller than the beam diameter, the resolution is inadequate for feature detection and measurement.

Spot diameter is usually specified in the center of the working range, but the limitations of physical optics dictate that it will not remain that size throughout the working range. The beam-shaping optics forms a beam waist at the standoff distance; at the extremes of the working range the beam diameter is larger (see Figure 5). The same rule of feature size detection holds true at the extremes of the working range, but the beam size is larger so the detectable feature size is larger also. The feature size detection



limitations of the beam diameter may be an important consideration for some applications.

Figure 5. The beam diameter is smallest at the standoff distance and wider at the limits of the working range. Thus, the minimum measurable feature size is smallest at the standoff distance and greatest at the top and bottom of the working range.

Receiver. The receiver/detector subsystem gathers the light reflected off the target and images the light onto a detector. The detector then reports the spot position to the processor, which determines the range or height. Of the many types of optical detectors available, two are most commonly used for laser triangulation sensors: position-sensing detectors (PSDs), and pixelized array detectors, also known as arrays. Each type has limitations and capabilities.

PSDs are analog detectors. PSD-type triangulation sensors use single-dimension detectors with electrical current outputs at each end. The amount of current from each output is proportional to the spot's position on the detector. If the spot is in the middle of the detector, the two outputs will be equal; as it moves off center, the two outputs change and spot position can be calculated from the relative change (see Figure 6).

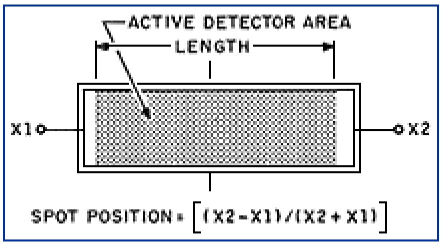


Figure 6. Position-sensing detectors produce two electrical current outputs that vary in relation to spot position. Therefore, the spot position can be computed from the difference in the two outputs.

One advantage of PSD-based systems is speed—the data rate can be on the order of 200 kHz. PSDs are efficient and the processing required to get an answer is simple. Another advantage is that an output will be given regardless of the intensity distribution of the spot. To an extent, this removes the effect of laser speckle from the system, albeit in a somewhat questionable manner. Speckle is an optical noise effect that limits the ability to determine true spot position.

One disadvantage of PSDs is that the centroid of the spot is determined by the detector. If two spots are present the detector will report a single centroid of both spots. Another drawback is that PSD systems are very sensitive to spot intensity. This is inherent in the detector and can be accommodated by additional circuitry. The effect of this sensitivity is that if the spot intensity changes while the spot position remains the same, the calculated position of the spot may change.

Pixelized array detectors are referred to as digital detectors, not in the sense of 0s and 1s but rather because their output is composed of discrete voltages representing the amount of light on each element of the detector. A 256-element detector consists of 256 discrete samples that constitute the output signal (see Figure 7).

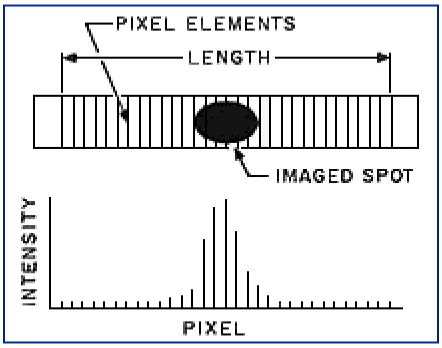


Figure 7. Pixelized array detectors produce a series of digital outputs that vary depending on the amount of light detected by each element of the array.

Array detectors require more postprocessing than do PSDs, and the data rates are normally slower. Furthermore, array detectors are usually larger than PSDs, making for a larger sensor package that may present integration problems.

Array detectors do, however, have a number of unique properties that make them of interest for triangulation sensors. The ability to "view" the intensity distribution of the imaged spot allows the user to truly understand the nature of the material or part being examined. There are many cases, such as threads or transparent materials, where there will be multiple spots on the detector. Without a digital detector the user may be unaware of this. Observing the detector output on an element-by-element basis allows the user to better understand the application.

Triangulation Terminology

Working Range. Area over which the sensor can gather valid measurements; the measurement range.

Standoff. Distance from the sensor housing to the center of the working range.

Spot Diameter. Diameter of the laser spot at the standoff distance.

Centroid. Weighted center of the laser beam spot on the detector.

The most important advantage of an array-based triangulation sensor is the ability to perform postprocessing on the signal. In the simplest form, the position of the spot is determined by performing a weighted centroid on the array data. If each pixel voltage is converted to an 8-bit digital word, the result is an array of 256 words ranging in intensity from 0 to 255. To calculate the centroid, use:

$$\text{Spot Position} = \frac{\sum_{i=1}^{256} I_i P_i}{\sum_{i=1}^{256} I_i}$$

Where:
i = pixel number (1-256 in a 256-pixel array)

This equation yields the centroid of the spot position in pixels and allows the triangulation system user to determine the location of the center of the spot to a fraction of a pixel.

Postprocessing. Processing electronics vary according to the type of detector used in the sensor. It should be apparent that the amount of postprocessing that can be performed depends on the amount of information available from the detector.

PSDs provide two electrical current outputs that are proportional to the position of the imaged spot on the detector. These currents are converted first to a voltage, then to a digital word via an A/D converter. The equation in Figure 6 [(X2 X1) / (X2 + X1)] is used to determine the spot's position on the detector. The only other information that can be derived from the PSD is that the two outputs can be summed together to measure the total optical power on the detector. But there is no way to determine any of the characteristics of the spot distribution or even the total number of spots on the detector. On the other hand, an array detector provides a large amount of information for postprocessing. The user can observe and manipulate multiple reflections, perform thresholding, and execute specialized digital filtering.

Thresholding. Thresholding is a technique used to selectively discard unwanted information. In the simplest case, thresholding can be used to filter out spurious reflections and noise in the sensor system. In Figure 8, the small-intensity values in the pixels that are not part of the real spot will slightly shift the spot's calculated centroid. It would be more obvious if the spot were at one end or the other of the detector. The horizontal line in Figure 8 indicates where the threshold would be set to counteract the effect of noise. By setting the threshold above the noise, all pixel values equal to or less than the threshold value are set to zero before calculating the centroid. This removes most of the optical and electronic noise from the image, ensuring that the resulting centroid calculation will not be biased.

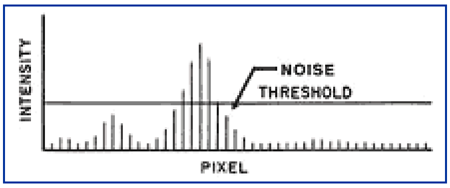


Figure 8. Setting a threshold eliminates noise and reduces distortions in the subsequent calculation of the centroid.

Another application of thresholding is the suppression of secondary images. Figure 9 is typical of a transparent glass or plastic component where the laser reflects not only from the top (first surface), but also from the underside of the material (second surface). There are two distinctly different spots separated by the thickness of the material. One spot has an amplitude greater than the other's because the amount of reflected light is greater from the first surface than the second surface.

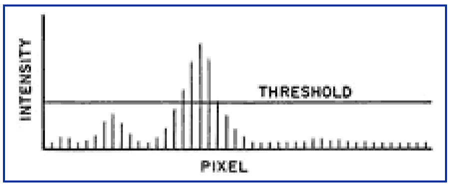
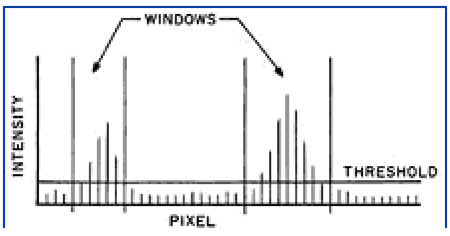


Figure 9. For transparent surfaces that reflect two images, thresholding is used to eliminate the secondary spot so that the centroid calculation is performed using only the primary output.

To determine the distance to the first surface, thresholding can be used to suppress the secondary spot; the result is that the centroid calculation is performed on the largest spot. If this measurement were made with a PSD detector system, the result would appear to position the centroid between the two spots.

Multiple Spot Images. Multiple spot images can be processed in a manner other than thresholding. This is useful for applications such



as measuring the thickness of a glass or plastic component or a coating. Such images are composed of two spots (see Figure 10). Multiple spot postprocessing can be accomplished by effectively segmenting the image into a collection of single images, sometimes referred to as windows, and calculating the centroid of each image. The resulting centroids are subtracted to determine the thickness.

Figure 10. For multi-spot processing, thresholding is used only to eliminate noise. The secondary and primary outputs are separated into windows, allowing each spot to be processed separately to identify both centroids. The difference between the two centroids is used to calculate thickness.

CyberOptics Digital Range Sensors

The digital range sensors (DRSs) from CyberOptics use a MOS linear array digital detector and a suite of postprocessing algorithms to produce high-resolution, high-accuracy performance. All the sensors are calibrated to NIST-traceable standards. The nonlinearity of the optical system is compensated for by the calibration of the sensor.

The sensors can be operated using a Windows 95/NT-based PC or the CyberOptics Model 1000 sensor controller module. The PC-based system, designed for applications requiring custom programming, consists of an ISA-compatible plug-in card and a developer's kit for writing software. Where custom programming is not required, the easy-to-use sensor controller offers a wide selection of parameters and settings, and needs no additional programming.

Linearization

Optical systems used in diffuse triangulation sensors are inherently nonlinear. Because the receiver system views the target from an angle, the motion of the received spot on the detector is not a 1:1 correlation with the change of height of the target. A good test of the nonlinear behavior of a triangulation sensor is to compare the reported change in height against the actual change. This can be done by moving a target through the working range of the sensor in known steps, and plotting the reported change in height against the actual. If the system is linear, by design or internally corrected, the plot of the two parameters will be a straight line. Any deviation from a straight line is a measure of the linearity.

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