Sherlock 7 Technical Resource

Teledyne DALSA Incorporated
Industrial Products

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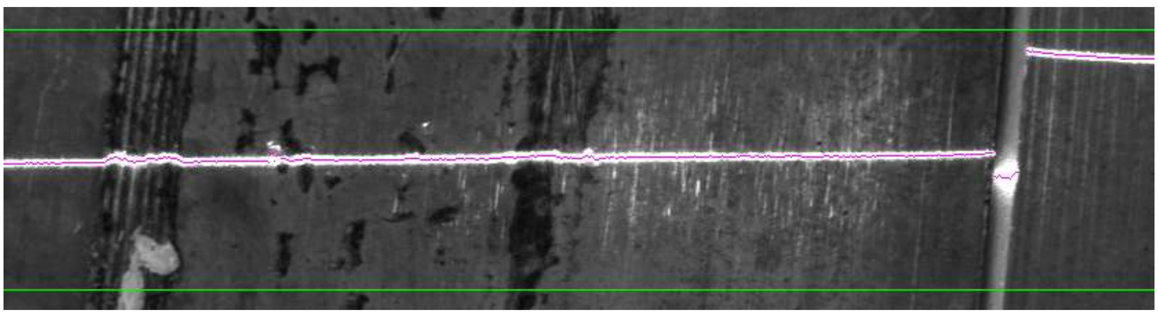
Laser Tools



Laser Tools used to check the placement of protective wrapping on high-pressure pipe. At the right, a gap in the wrapping is followed by lifting of the wrapping, shown by the upward step in the reflected laser line points.

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Laser Tools – Introduction

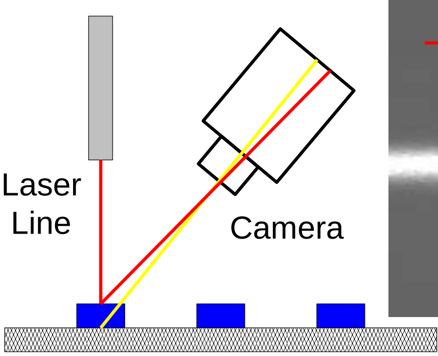
The Laser Tools measure positions of bright points within an ROI. These bright points are usually from a line of light generated by a laser and reflected off of a part. However, any source that produces bright points can be used. In this document we call these bright lines “laser lines”, even if they are not made by a laser.

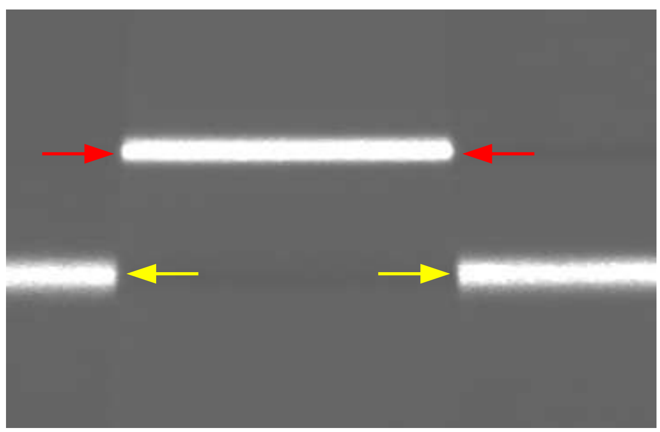
These tools include:

Laser Caliper	Measures the width of a reflected laser line
Laser Points	Reports the position of bright points in an ROI
Laser Line	Fits a Sherlock line to the bright points
Laser Height	Measures the height of a surface using a laser line

Laser Height is the most commonly used tool. Laser Caliper, Points, and Line could be done with other Sherlock tools, but they are designed to be easier to use on laser lines.

This drawing shows a laser and camera set up to measure a height profile across cylindrical pills on a conveyer belt:





Camera view across pill width

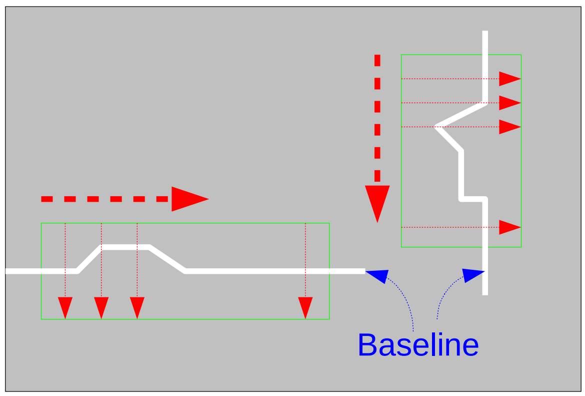
As a pill passes under the laser line the laser line is reflected into the camera. The laser line extends in and out of the page in this drawing. The conveyer belt is the *baseline* (the reference point for height measurement) and reflects the laser beam as shown in yellow. This appears as the lower line in the camera’s image on the right. The pill reflects the laser beam into a different position in the camera, marked in red. The height of points on a pill is thus translated into shifts in point positions in the camera’s image. Broken pills will not have the clean height profile shown in this image.

Each image gives heights along a *profile* of the pill. Multiple profiles could be combined to make a *surface map* of the pill. The part or objects being measured for height must have reflect enough of the laser line light into the camera to be imaged.

Rules for all Laser Tools

Laser Caliper scans a line ROI in the direction of the ROI's arrow.

The other laser tools scan a rectangular ROI looking for dark-to-light and light-to-dark edges of bright points (reflections of a laser line off of an object). A horizontal laser line's ROI is scanned from top-to-bottom, left-to-right, and scan a vertical laser line's ROI from left-to-right, top-to-bottom. This diagram shows a horizontal and vertical laser line with the first three and one last "scan lines" drawn as red arrows within the ROI. The dashed red arrow outside the ROI indicates the secondary direction of scanning.



You need to know the ROI scanning direction to set up the laser tools and to interpret output readings.

All laser tools expect the first bright point edge in the primary scan direction to be dark-to-light and the second edge to be light-to-dark, and will report an error if this is not the case.

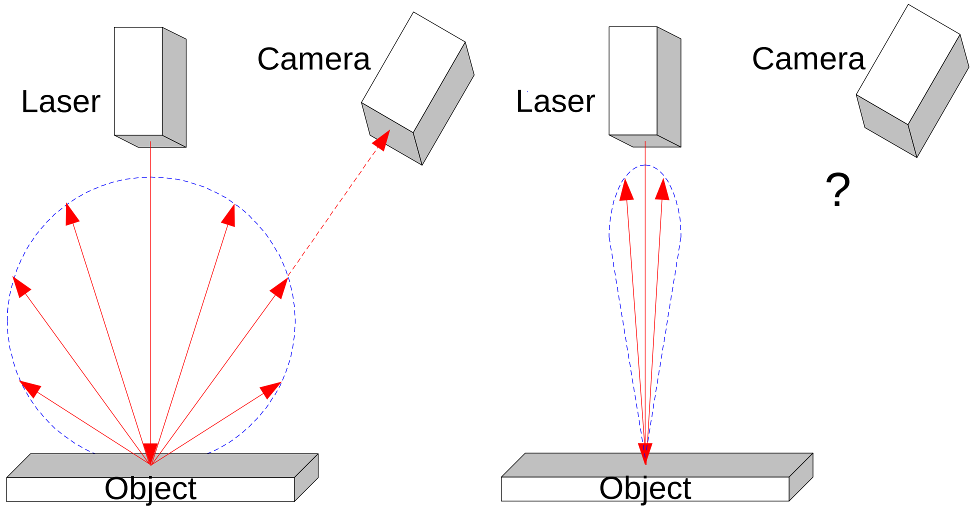
All laser tools require setting the approximate width (from edge to edge) of the laser line. This value sets the size of the edge detection kernel. If the reflected laser line is thicker than the range of allowed widths, simply use the largest width.

All tools require a threshold for edge detection, in the range of 1 to 1024. The outputs from the edge detection are scaled to this range and edges with "strength" below this threshold are ignored. This helps prevent detection of weak or noise edge points.

Point outputs are in Image Window coordinates, with 0,0 at the upper,left of the Image Window. Laser Height measures heights from a baseline (blue text and arrows in the above drawing) upwards for a horizontal laser line and leftwards for a vertical laser line.

What Types of Objects?

The Laser Tools depend on light from a laser line (or another line light source) reflecting off of the object and into the camera. We represent the reflection intensity at different angles by the length of arrows from the reflection point:



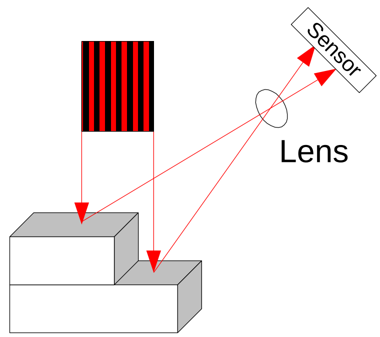
The Object on the left has a diffuse or matte surface (such as paper or low gloss plastic) that scatters light at many angles, and so into the camera. On the right, a reflective surface (such as metal) scatters light back towards the laser, with little or no light entering the camera. Some surfaces may have an asymmetric scattering distribution, so you can get a stronger signal by placing the camera at the peak scattering angle. Most objects have a combination of diffuse, shiny (specular), and complex (Fresnel) reflection components.

Surfaces, such as metal or high-gloss parts are difficult or impossible to “see” with a laser line because there is not enough off-axis reflected light to the camera. If there is some off-axis reflection, increasing the laser power might get enough light into the camera to make measurements. A different wavelength of laser line light might also increase the amount of light reflected into the camera.

Objects with reflective surfaces can also produce multiple reflections that complicate height measurements. The Laser Height algorithm has a special mode to suppress these unwanted reflections.

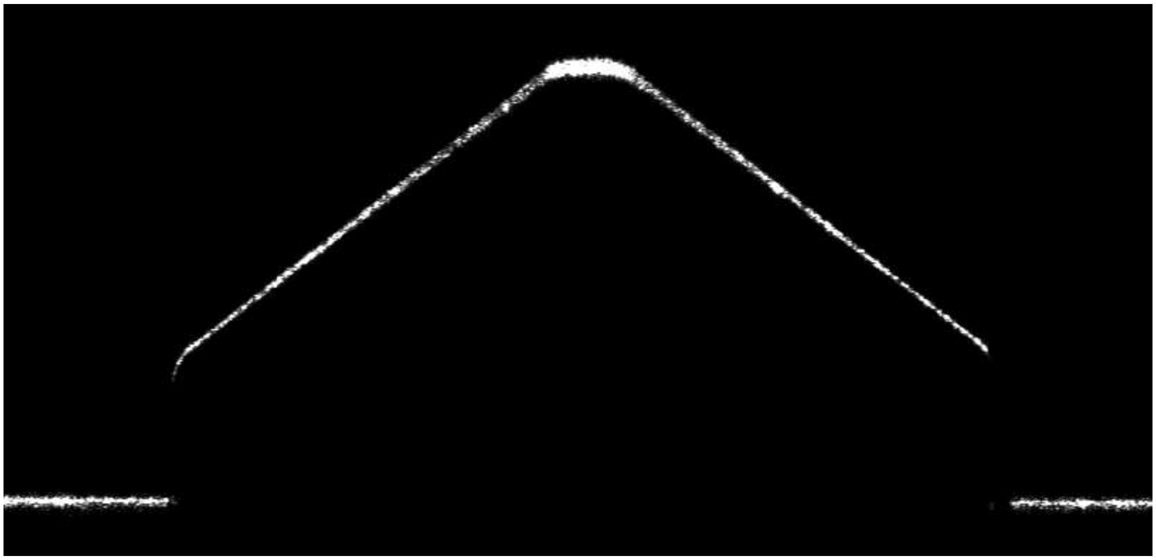
Laser Selection

Laser lines are good for height and other measurements as they are intense and can be tightly focused. This decreases the chance of multiple reflections from different object points and increases the contrast of the measured bright points in the image. A thicker line of light might reflect from more than one surface height giving multiple, lower contrast points of light in the camera. In this figure a thick light beam (from the top) produces multiple reflections from different heights into the camera (two diagonal red lines):



Another advantage of a laser line is that you can use a narrow band-pass filter on the camera's lens to block ambient illumination and pass only the laser wavelengths. This increases the contrast for measured bright points when the laser system can't be shielded from ambient illumination.

Laser lines may appear rough or speckled due to reflections from different heights and due to self-interference within the beam. This speckle limits the accuracy of bright point measurements and hence the height measurements. Incoherent illumination, say LED or incandescent light, does not have appreciable speckle, but can't be focused as thinly as a laser. This reflection of a laser line off of a smooth metal part shows speckle:



Red diode lasers are the most common in machine vision and usually the lowest cost. Cameras generally are more sensitive in the green portion of the spectrum, to match human vision, so a green laser might give a better signal – brighter points in the camera's image.

Painted or pigmented materials reflect their color and absorb other colors. So a red laser is fine on un-pigmented or red materials, but will give a weak signal on green and weaker still on blue pigmented materials. So for blue or green pigmented materials, a green laser should be used (blue lasers are quite expensive).

Stocker and Yale's Lasiris division[1] and other vendors provide laser line products.

As the object's off-axis reflectance decreases – the object is dark and absorbs most of the laser light or it reflects the laser light back to the laser and not into the camera – a more powerful laser is needed. Lasers with power from 1 to 40 mW are commonly used.

Laser Safety

Any laser beam can discomfort or damage people because the light is so concentrated. The lens or holographic optics that forms the laser beam into a laser line reduces the power density but safety measures are still required. Laser beams and laser lines should be set up to prevent direct viewing. Lasers under 5 mW require a warning label and warning light indicating that they are on.

Lasers over 5 mW (FDA class IIIb or IEC class 3B or higher) require a warning label and light and could require additional safety measures such as an enclosure with interlocks that prevent viewing the laser beam, external warning lights when the beam is active, and a time delay to give operators time to get out of the beam or line area.

TELEDYNE DALSA cannot give you advice on laser safety. We can only warn you that required and prudent safety measures should be included in your laser height system design. For professional advice on laser safety requirements, consult a laser safety expert, the laser manufacturer, and standards for laser safety[2].

[1] http://www.stockeryale.com/i/lasers/index.htm
[2] http://www.fda.gov/cdrh/aboutcfr.html and http://www.fda.gov/cdrh/radhealth/products/laserfaq.html

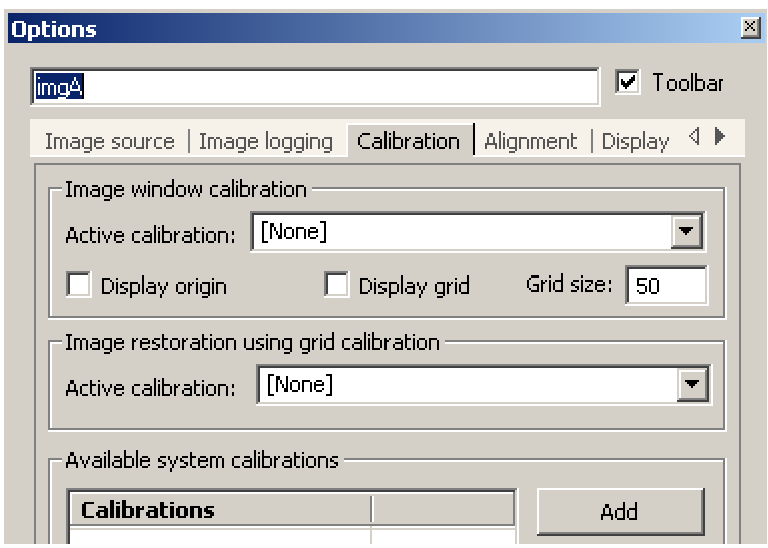
Lens Selection

The lens must provide an undistorted, well focused, high contrast image of the reflected laser line across the part being measured. The Teledyne DALSA LensHelp program (available from IPD or IPD partners) can help you select the appropriate lens. Here are two additional considerations for lens selection.

Perspective and Optical Distortion

Perspective distortion is the apparent reduction in object size with distance. Optical distortion is the apparent curving of straight lines off of the center of the lens. A "fish eye" lens is an extreme example of optical distortion. Both distortions reduce height measurement accuracy. Both distortions decrease with longer focal length, so use the longest focal length lens you can. For high accuracy, use a telecentric lens, as this kind of lens has little perspective or optical distortion.

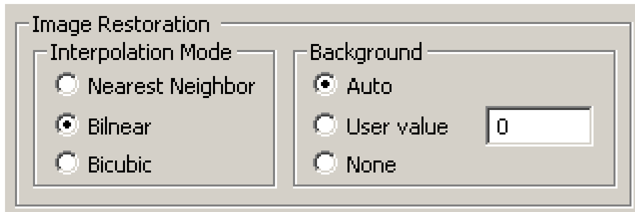
Sherlock has two methods to compensate for distortion effects. Open the Options dialog by clicking the double-checkmark icon . Select the Calibration tab to get a dialog that looks like this:



"Image window calibration" should <u>not be used with Laser Height</u>. In Laser Height, an array of point reading (output) is used to specify which points have valid heights, as some points on the object might not be visible due to absorption of the laser line or being obscured by other parts of the object. "Image window calibration" can change the values in the point reading array, making it difficult to know which points were measured.

"Image restoration using grid calibration" can be used to reduce optical distortion. This "restores" the image by doing the inverse of the optical distortion. The resulting image is then processed. Note that the resulting image can be reduced in size, so keep your measurement ROI away from the image edges.

To use “restoration”, follow the Sherlock manual’s instructions for doing a calibration. When you click the Grid Calibration button to set up the calibration, also set up the Image Restoration parameters:

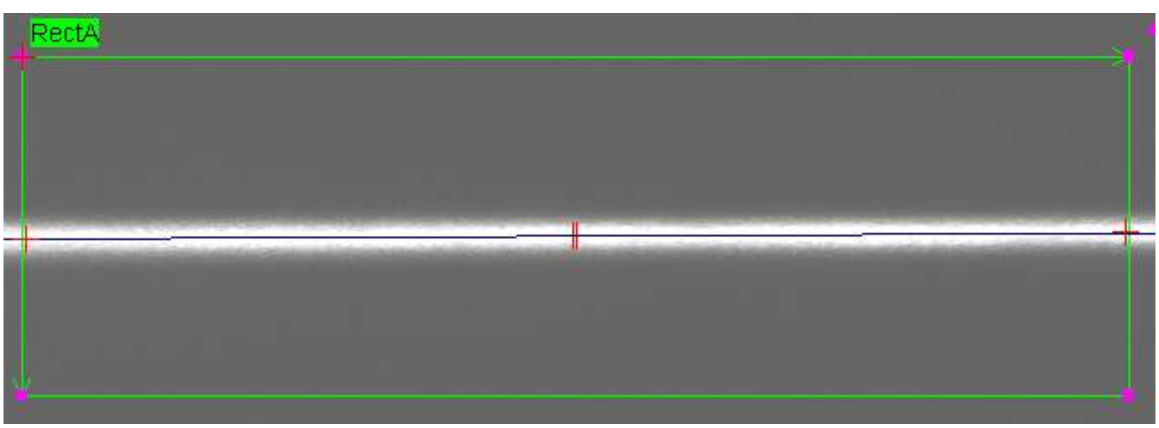


The input image is re-sampled (“warped”) by restoration, so interpolation is required. The default is Bilinear but we recommend the slower Bicubic interpolation as it has better accuracy. The Background selection gives the image color (intensity) to fill in image areas that have been reduced in size by the restoration. Auto lets Sherlock select the fill intensity based on the pixel values at the edges of the image. User value lets you select a value, and None means that no changes to the background are made at the image edges.

In the parent (main calibration) dialog, in “Image restoration using grid calibration”, select your calibration (e.g. CalibrationA) as the “Active calibration”.

Image restoration can improve the accuracy of the Laser Tools when there is significant optical distortion. With longer working distances and so longer focal length lenses, the improvement in accuracy from image restoration might not be worth the setup and computation time.

As an example, a high-quality 25 mm lens with a 20 cm working distance and a 33 mm field of view shows very little optical distortion and so the benefit of image restoration is slight and might not be worth using. Here is what Laser Line looks like in this case:



You see some small rotation but no curving of the laser line due to optical distortion.

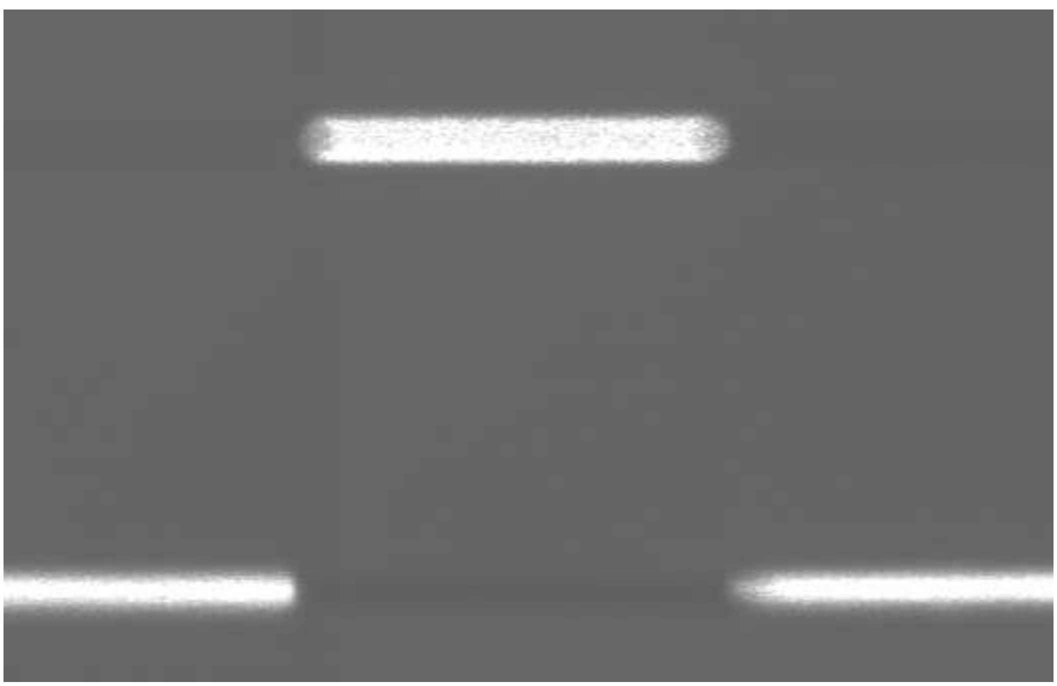
Line Broadening

The laser line optics should be focused to a narrow line over some depth of field. As described in the **Laser Selection** section, a narrow line reduces reflections from multiple heights, and increases the brightness of the reflected line points in the image.

Lenses also have a depth of field – the height range that they can sharply focus the reflected laser line onto the camera's sensor. As object height changes, the laser line reflection will broaden as it goes "out of focus". Some broadening is acceptable if (1.) the line broadening is symmetric around the center line of the reflected laser line and you are using the centers of the bright points for measurement, and (2.) the reflected line's contrast is sufficient for reliable detection of line edge points. Large amounts of defocus broadening will decrease accuracy because light from a position on a profile will mix with light from neighboring positions.

So, for best accuracy, try to keep line broadening to a minimum. This can be done by decreasing the height range measured or by stopping down the lens.

In this image of a laser line reflected off of a calibration block, you can see significant line broadening at the top of the calibration block due to the limited depth of field of the lens:



Camera Selection

Use a monochrome, area (not line scan) camera. A color camera could be used (for example if you were also checking the color of a product using additional white light illumination), but be careful because the color filter pattern used in most color cameras will not pass much red laser light at the green- and blue-filtered pixels. This could lead to gaps in the measurements or incorrect measurements.

There are additional requirements for cameras used with Laser Height – see the **Camera Selection for Laser Height** section in the Laser Height algorithm.

Filter Selection

If the height measurement system is not in a light-tight enclosure, ambient illumination can decrease the contrast of bright points and hence their measurability. Placing an optical bandpass filter over the lens can block most of the ambient illumination and make the contrast high on reflected laser line points.

For example, a 635 nm red laser line would need a 635 nm bandpass filter on the camera's lens. Various manufactures make these filters specifically for machine vision[3].

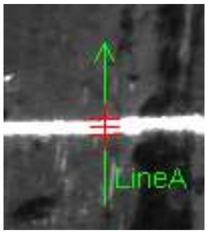
There are times when you want some ambient illumination so that you can do other inspections on the part while it is being measured for height.

[3] http://www.machinevisionfilters.com/ for example.

Laser Caliper [Algorithm]

Laser Caliper measures the width of points on a bright line in an image. It is like the Outside Calipers algorithm but simplified and specialized for laser lines. Place the line ROI perpendicular to the reflected laser line.

This image shows Laser Caliper applied to a reflected laser line. Side and center points are marked with red + annotations. The width of this line is reported as 8.57 pixels:



The ***line width*** parameter is an initial guess at the width of the laser line. You should adjust this parameter to be about the actual width of the laser line. Larger line width values help reduce noise but can also reduce the accuracy of the caliper measure.

Min. strength sets the minimum edge strength. This threshold is used to suppress low intensity lines due to noise or reflections of the laser line.

Laser Caliper outputs:

valid – True if the caliper measure could be made – that is, there was a bright line across the caliper and both edges of the line were above the ***min. strength*** threshold.

strength – The average edge strength of the two edges used in the caliper measure.

side A – The X,Y position of the first edge (side of the laser line) found in the direction of the line ROI arrow.

side B – The X,Y position of the second edge found in the direction of the line ROI arrow.

center – The X,Y position of the center between the A and B side calipers.

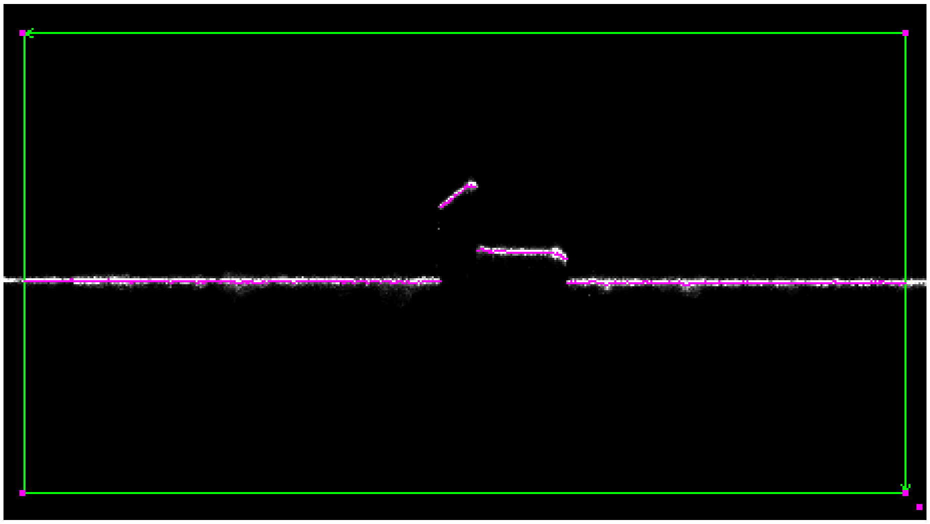
thickness – The distance between the A and B side calipers

Laser Points [Algorithm]

Laser Points returns arrays of points for the positions of sides and centers of the bright points made by reflecting a laser line off of objects.

Points are found by scanning vertically or horizontally, so rotate the camera and laser to make the reflected laser line nearly horizontal or vertical in the image. If that is not possible, rotate the ROI to make the line nearly horizontal or vertical within the ROI. Rotated ROIs have interpolation errors, so rotating the laser and / or camera is preferred.

This image was made by projecting a laser line onto a flat surface with an L-shaped part resting on that surface (the "baseline"). The lowest points (vertically) are reflections of the laser line from the baseline and higher points are reflections from the part and could be used to compute part heights. The centers of points found by Laser Points are shown in magenta. Default annotations for the sides (edges) and centers of the points are turned off, as they obscure the center point positions.



Set the ***line width*** parameter to the approximate width of the laser line (you can get an estimate using a line ROI with the Laser Caliper algorithm).

Set the ***min. strength*** parameter to the change in intensity (edge strength) needed to detect laser line points.

Set the ***direction*** parameter to specify the direction of the laser line. Your options are:

- horizontal The laser line is horizontal (as in the above image)
- vertical The laser line is vertical
- automatic The algorithm finds the direction (horizontal or vertical) of the laser line.

The default is "automatic", but the algorithm will be faster if you set ***direction*** to either "horizontal" or "vertical".

Set the ***edge*** parameter to either:

- find maximum	Maximum contrast edges are found (default)
- find first	First edges with contrast more than ***min. strength*** are found

The "find first" option can sometimes prevent secondary reflections off of the object from being used as measurement points. See the **Secondary Reflections** section in the Laser Height algorithm.

The ***display*** parameter selects additional annotations for the points' centers, edges or both. The standard point annotation (a red + mark) obscures the edges, so we recommend turning this annotation off (double-click the point array in the Program window and set the "Display in image window" field to [None]) and turning on this additional annotation for point centers. Your options are:

- none	No additional annotation (default)
- center	The center points are marked with magenta dots
- edges	The side (laser line edges) points are marked with red dots
- all	Both the center and side points are marked

The following output readings are returned. Sherlock returns point values in Image Window coordinates:

valid – At least one point along the laser line was found and both edges of that point were above the ***min. strength*** parameter.

strength – The average of the edge strengths of the two laser line edges over the entire laser line. This value is normalized to be in the range of 0 to 1024. 0 is returned when "valid" is false.

num. points – The number of points measured along the laser line. 0 is returned when "valid" is false.

side A – An array of points holding the positions of the first edges (dark-to-light) of the laser line, found while going from top to bottom on a horizontal laser line ROI or left to right on a vertical laser line ROI. If "valid" is false, this array is empty.

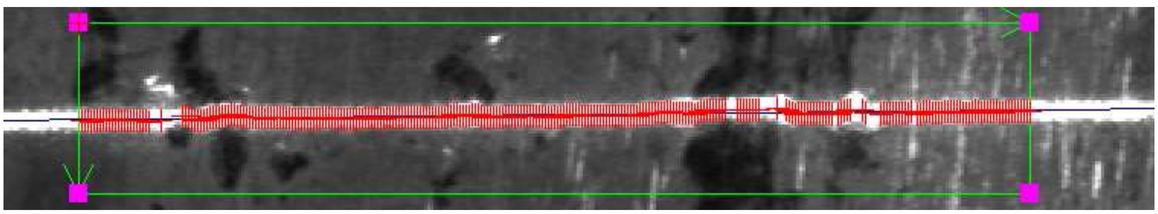
side B – An array of points holding the positions of the second edges (light-to-dark) of the laser line, found while going from top to bottom on a horizontal laser line ROI or left to right on a vertical laser line ROI. If "valid" is false, this array is empty.

center – An array of points holding the averages of each point's "side A" and "side B" positions. These center points approximate the centers of the laser line points. If "valid" is false, this array is empty.

Laser Line [Algorithm]

This algorithm fits a Sherlock line to the laser line. It can be used to find a baseline (the points reflected from a flat, reference surface) for laser height measurement, or to measure the rotation of the laser line. A second process in this algorithm detects an end point (*tip*) of the fit line.

In this image, points along the laser line that are used in the Sherlock line fitting are marked with red crosses. The fit line (in blue) can be seen extending out of the ROI to the left and right. Laser Line can automatically remove points whose positions deviate significantly from the majority of the points – that is why some red crosses are missing.



There are two groups of parameters for Laser Line: Line and Tip

Line Parameters

Set the ***line width*** parameter to the approximate width of the laser line. You can get an estimate for ***line width*** by using a line ROI with the Laser Caliper algorithm.

Set ***min. strength*** to the minimum change in edge strength needed to detect a laser line.

Set ***direction*** to specify the direction of the laser line in the image. Your options are:
- horizontal	The laser line is horizontal (as in the above image)
- vertical	The laser line is vertical in the image
- automatic	The algorithm finds the direction (horizontal or vertical) of the laser line.

The default is "automatic", but the algorithm will be faster if you set ***direction*** to either "horizontal" or "vertical".

use specifies which points along the laser line to use in the line fitting:
- side A	Use the first edge points (dark-to-light) of the laser line found while going down the ROI if using horizontal laser line, or from the left if using a vertical laser line.
- side B	Use the second edge points (light-to-dark) of the laser line found while going down the ROI if using a horizontal laser line, or from the left if using a vertical laser line.
- center	Use the center points of the laser line – the bisector of lines between side A and B. This is the default and usually gives the most stabile measurements.

Set the ***% outlier ignore*** parameter to the percent of points in the laser line to ignore because they deviate from the majority of the laser line points. If you are measuring an essentially straight baseline, set this to 0 or a few percent. The range is 0 to 50% with a default of 5%. The larger the **% outlier ignore**, the slower this algorithm runs.

If ***display*** is true, this algorithm will output magenta dots that indicate the points used in the line fitting. If false (the default), the points used in fitting are not marked with magenta dots. The points are marked by default with the point annotation (a + mark). To see the magenta dots, turn off default point annotations for this algorithm.

Tip Parameters

The Tip Parameters are used to find the end or *tip* of a reflected laser line or other bright line. This can be used, for example, to measure the gap between two segments of a reflected laser line.

The ***find tip*** parameter specifies which tip of the reflected laser line you want to find. If there is no end or tip within the ROI, then no tip is reported (the "valid tip" output is false). Only one tip is reported, so arrange the ROI so that there is only one tip within it.

find tip looks for an intensity transition. For light-to-dark and dark-to-light transitions, lines are scanned from left to right (for approximately horizontal lines) or top to bottom (for approximately vertical lines).   The choices for ***find tip*** are:

- none		Don't look for a tip (algorithm will run faster)
- strongest	Find the tip with the greatest contrast to the background (default)
- light-to-dark	Find the tip where intensity transitions from light to dark.
- dark-to-light	Find the tip where the intensity transitions from dark to light

tip end filter sets the size of the differentiating filter used to find the tip. Increase this value for tips with long gradients (slowly changing intensity) or with lots of image noise. The default value of 4 usually works well.

shift tip search shifts the position of the tip search by the specified number of pixels from the position of the Sherlock line at the tip. This is used when the Sherlock line "misses" the end (tip) of the laser line and allows you to adjust the tip search area up or down (or left or right) to find the tip of the laser line.

These output readings are returned:

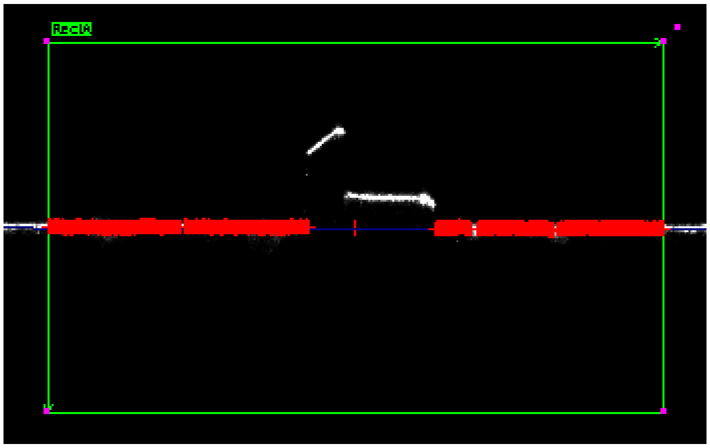
valid line – returns true if there were enough edge points above the ***min. strength*** parameter that the algorithm could fit a line. This does not guarantee that the line you would pick was found by the algorithm.

valid tip – returns true if a tip was found in the ROI, of tip type specified by ***find tip***.

line strength – The average of the edge strengths of the two (side A and B) laser line edge points used in the line fitting . This value is normalized to be in the range of 0 to 1024. 0 is returned when “valid line” is false.

tip strength – The strength of the detected tip. 0 is returned when “valid tip” is false.

The remaining Output readings are best described by example. Here is an image showing the outputs from the Laser Line algorithm:

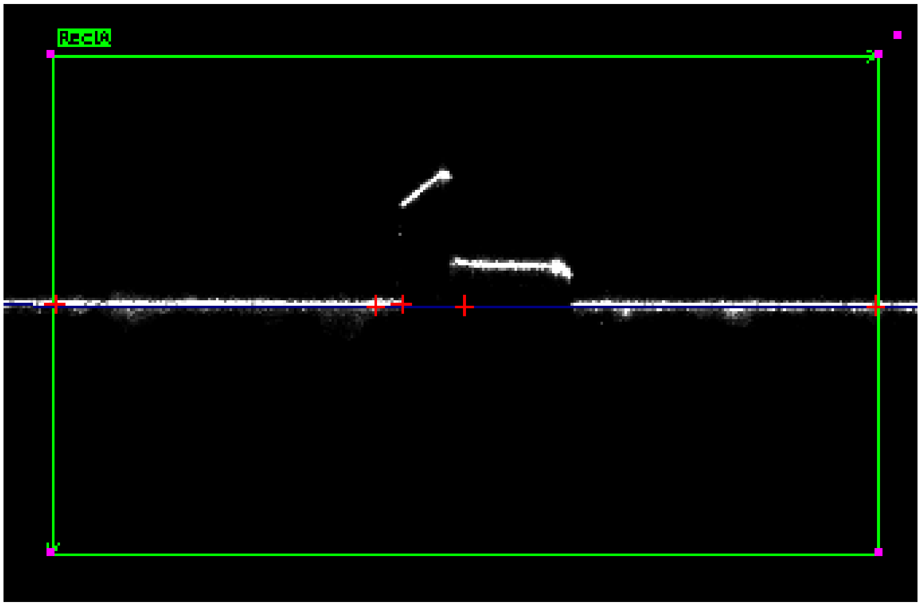


This has the default (red +’s) annotation to show the points used in line fitting. In this case 22% of the points were ignored (parameter ***% outlier ignore*** = 22) so that the points above the baseline (the higher points near the center of the ROI) were not used in fitting the baseline.

The points used in fitting are in the “line points” array reading. These are the values that generate the red +’s.

The fit line is shown as blue and is obscured by the default point annotation except near the center of the ROI. The angle and intercept for this line are returned in the “line” reading.

Turning off the default annotation for the line points reading shows the other output readings:



With the default annotations for line points off, you can see five red +'s. Starting from the left they are:

p1 intersect – The first point where the fit line first intersects the ROI (the "entry" point). Left to right scan for nearly horizontal lines and top to bottom scan for nearly vertical lines.

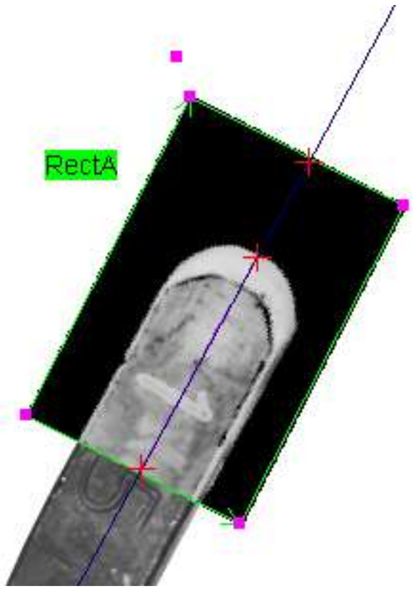
points middle – The middle of the fit points used. This is the middle of the set of points when ***% outlier ignore*** points have been removed.

Tip – The end point of the laser line. An end point is where the laser points move off the baseline or disappears. In this example, the line "ends" when it suddenly jumps upward. Only the single end point with the strongest contrast or strongest light-to-dark or dark-to-light transition is returned, even if there are more ends to the laser line, as in the above image. If you want to find a particular tip, make sure it is the only end point in the ROI.

line center – This is the center of the fitted line within the ROI, so the midpoint between "p1 intersect" and "p2 intersect".

p2 intersect – The second point where the fit line intersects the ROI (the "exit" point)

Laser Line's "tip" algorithm can be used to find the endpoint of an object. Here, for example, we use Laser Line to find the "tip" (end point) of a horseshoe:

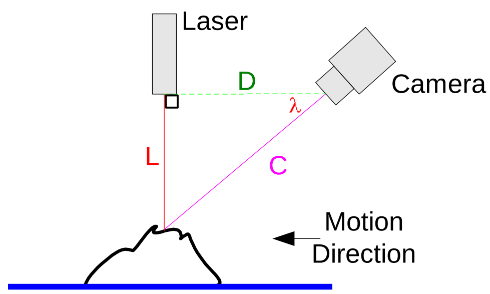


To meet laser tools' requirements, we (1.) invert the image contrast in RectA so it appears as a bright "laser line", (2.) have only one (very thick) "line" made by the horseshoe metal, (3) have only one tip in the ROI, and (4.) we rotate the RectA so the end portion of the horseshoe is approximately horizontal in the ROI.

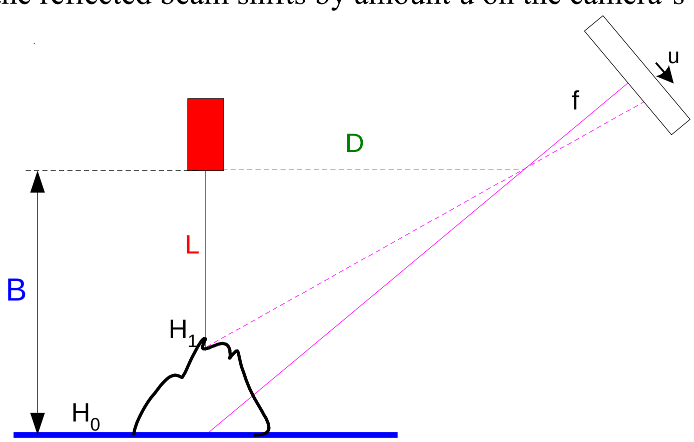
Laser Height [Algorithm]

Laser Height measures a line of object heights using laser line of light reflections off the object. A single line of height measurements is called a *height profile* or just a *profile*. The profiles can be used to build a 3D *surface map* of a part. If you are familiar with laser height measurement, skip to the **Summary of Optical and Physical Setup** section.

In this drawing, a laser projects a line of light onto the surface of an object, shown as a black outline. The object rests on a blue *baseline*, perhaps a conveyer belt, which is the reference plane for height measurements. The line of light goes in and out of the page, so we are looking at one point of height profile across the object. The object's surface is diffuse enough to reflect laser light (red line L) into the camera (magenta line C). D is a known, fixed distance between the laser and the camera's lens nodal point.



The angle between L and D is 90 degrees. The angle λ, between C and D, changes with object height. The distance of each reflected point from the laser is: $L = D\tan(\lambda)$ This method is known as *triangulation*. If the angle between L and D is not 90 degrees then the "Law of Sines" is used to compute L. λ can be computed from shifts in the imaged positions of reflected laser line points. For example, as object height changes from H0 (baseline) to H1, the reflected beam shifts by amount u on the camera's sensor:



Here f is the back focal length of the lens and B is the distance to the baseline (H_0), so the height of point H_1 = B - L.

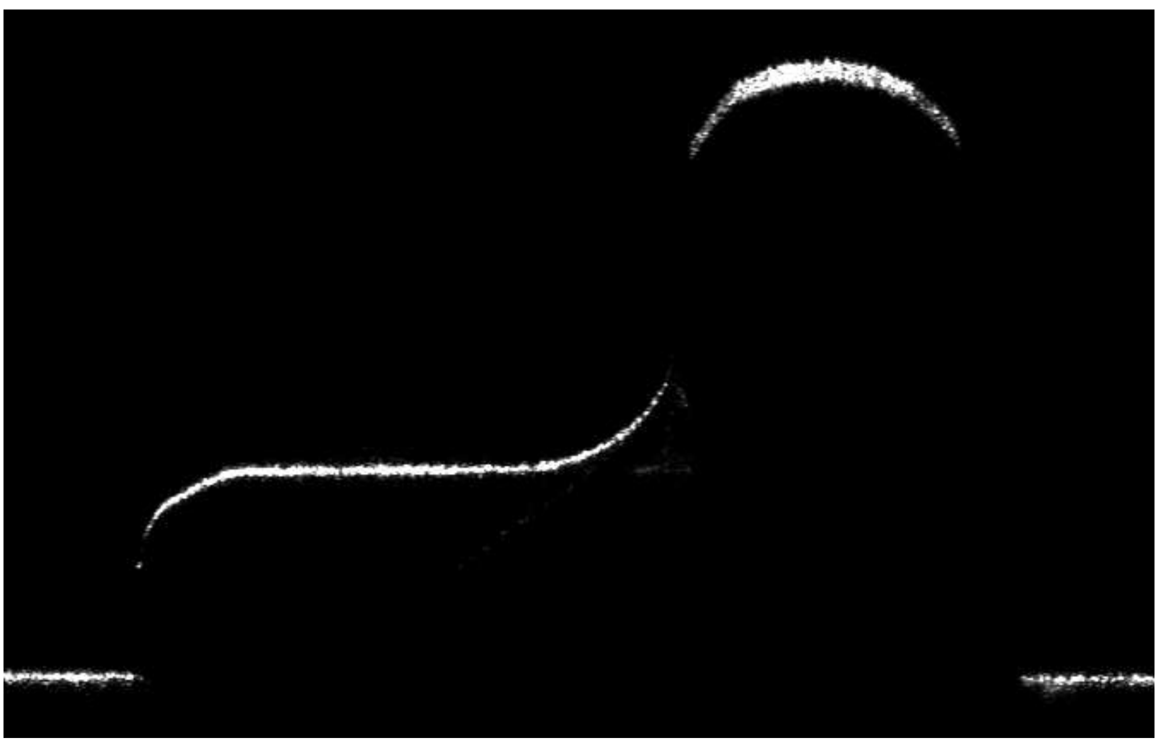
Triangulation requires that you know the values of D (laser to lens node distance), the angle between D and L (the laser beam), the angle of the camera's optical axis with respect to D, and f, the back focal length of the lens. You also need to calibrate the height measurement to account for inaccuracies in these parameters and distortions.

These values for triangulation are difficult to measure with sufficient accuracy and the calibration can require many measurements to build a look-up table of point shifts (u) on the sensor to heights.

Laser Height extracts these triangulation values simply by calibrating at three known heights. You don't have to exactly measure the triangulation values or go through a long calibration process. You can put the camera and laser at convenient positions with respect to the object to be measured, and Laser Height recovers the appropriate values from the calibration process.

Laser Height's accuracy is comparable to fixed laser height systems if you follow some recommendations. A Laser Height system is simpler, costs less, and is much more flexible than a fixed laser height system.

This image shows reflected laser line points shifted vertically on the camera's sensor (shown as u in the drawing) as a function of height. From these shifts we compute λ and this gives the part height using Laser Height's calibration.



Note the "speckle" of the reflected laser line and the "broadening" of the line as it goes out of the (lens) focus. These artifacts were discussed in the introduction.

Camera Selection for Laser Height

Laser Height requires an area scan, not a line scan, camera. While color area scan cameras could be used, the color filter pattern in most color cameras will lead to gaps in the height measurements or incorrect height measurements. See the Camera Selection section, in the introduction, for more details.

A camera's pixel dimensions set the resolution for the profile sampling and for the height measurements. For example a camera with pixel dimensions 1024 x 768 (width x height) and used with a horizontal laser line, will have a profile (X) resolution of 1/1024 and a height (Y position) resolution of approximately 1000 (slightly better than 768) due to sub-pixel interpolation of the height measurement.

The camera's frame rate must be fast enough to measure the required height profiles. If, for example, you are taking a single profile across an integrated circuit package's leads, then a modest frame rate – perhaps one or two images a second – would do. However, if you are building a 3D *surface map*, then the frame rate might have to be much higher to get the required resolution in the surface direction perpendicular to the profile.

Teledyne DALSA makes cameras with high frame rates, such as 500 frames per second. However, it becomes difficult and costly to transmit and process the huge number of pixels coming from a high frame rate camera. One solution is to use a Teledyne DALSA "smart camera" that run-length encodes the pixel information. As most pixels are black, this can reduce the amount of transmitted and processed data by a factor of about 1000 (for a 1,000 x 1,000 pixel camera). Contact Teledyne DALSA for more details.

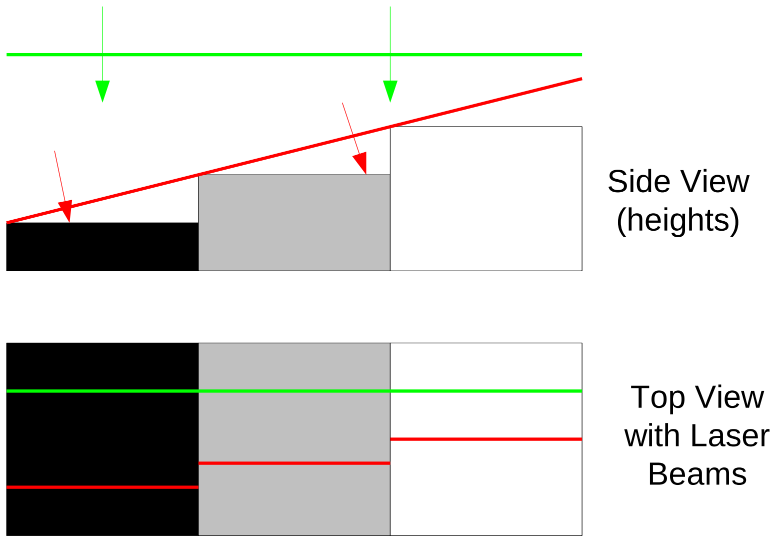
Physical Setup Recommendations

By this point you should have a laser, lens, camera, and possibly a filter and you should have experimented with these components to confirm that you can get good reflections of the laser line from the part being measured into your camera. Here are recommendations for setting up these components for good height accuracy.

Configurations

There are two general configurations of the camera and the laser. The "laser above" configuration puts the laser above and perpendicular to the part being measured, and the camera at some angle to the side of the laser. The "camera above" configuration puts the camera above and perpendicular to the part being measured, with the laser at some angle to the side of the camera. Laser Height can accommodate both configurations but, when possible, we suggest using the "laser above" configuration.

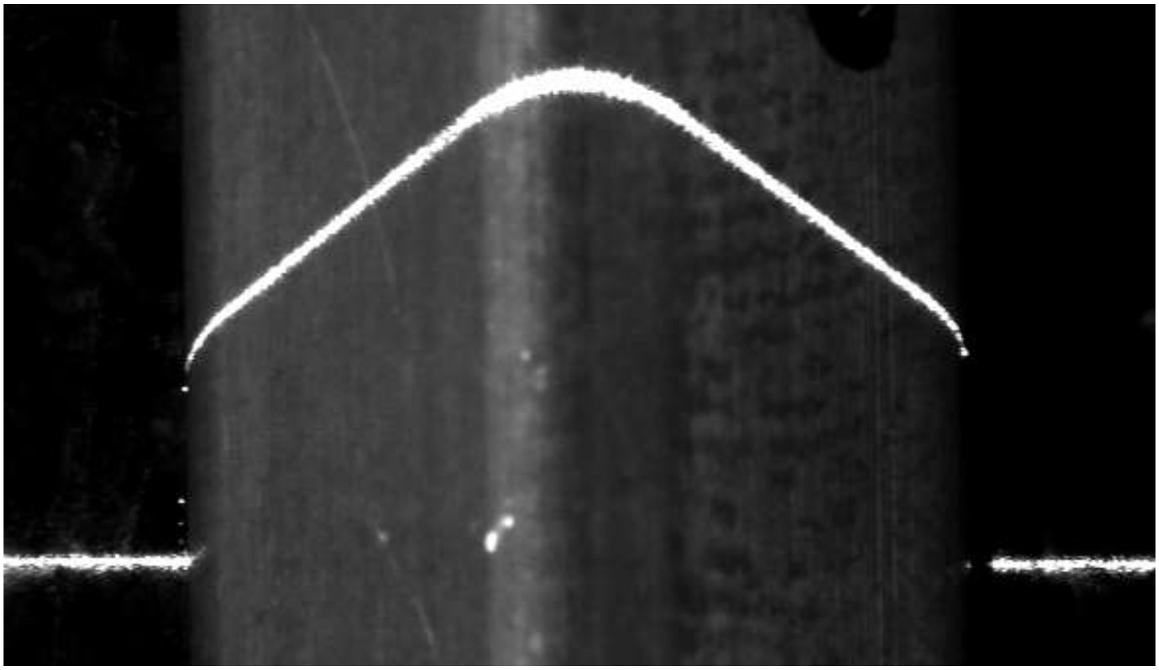
The "laser above" configuration measures the heights along a line profile, while the "camera above" configuration measures heights in locations that depend on the height itself. In this drawing, the “laser above” line of light is in green and the “camera above” line of light in red.



“Side View” shows the laser beams hitting an object with three steps of height, black is lowest, then grey, and white the highest. The “Top View” shows what you would see looking straight down, perpendicular to the part. As you are on the same axis as the “laser above”, the green line is straight and shows that heights on the part are all sampled along a line. However, still looking straight down, you see that with “camera above” (and the laser at the side) the heights are sampled at different positions on the object.

Because the “laser above” configuration samples heights on a straight line profile, it is much easier to know where you are sampling and to build a 3D surface map from successive profiles.

You could use the “camera above” configuration if you don’t care where you measure heights, for example, getting statistics on the height of ore on a conveyer belt, or when the part being measured has the same height profile in the direction perpendicular to the laser line. In the next image, we are measuring the height profile on a V-shaped metal extrusion, placed upside-down on a flat surface. The extrusion has the same height profile vertically in the image, so the used “camera above” configuration is acceptable:



The part is also illuminated with some diffuse light, so you can see the measurements (bright points due to the laser line reflection) are taken at different vertical positions on the extrusion.

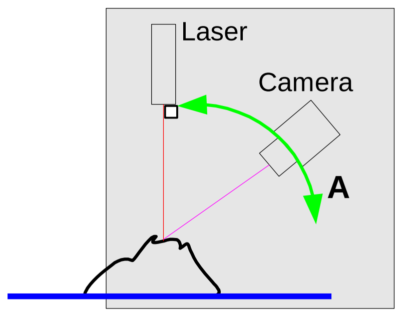
You could compute where the height measurements are made in the “camera above” configuration, but this requires measuring the position of part, camera, and laser, as well as the lens back focal length and the angles to the optical axis to good accuracy, and this is what the Laser Height algorithm avoids.

Geometry of Camera, Object and Laser

In what follows, we use the “Laser Above” configuration, but the same considerations and issues occur with the “Camera Above” configuration.

Laser Height works with either nearly horizontal lines where height increases vertically upwards or with vertical lines where height increases horizontally to the left. As vertical displacements are easier to see as “height”, in what follows we assume that your laser line (with no part in place) appears as a horizontal line in the image.

Try to have the laser, camera and part all in one plane, with that plane perpendicular to the laser line of light. Think of the laser and camera as mounted on a sheet of rigid material (like metal), show in gray in this drawing:



The laser is mounted flat in this plane and the laser line goes in and out of the image, as does the object. The baseline (reference point for height measurements) is in blue and also goes in and out of the plane. The camera is mounted in the same plane as the laser and at some adjustable angle, A, as shown by the green arc.

The camera’s optical axis (the center of the image) should be aligned such that heights in the middle of the measurement range give bright points that are approximately at the center of the camera. This can be adjusted by rotating the camera in the plane.

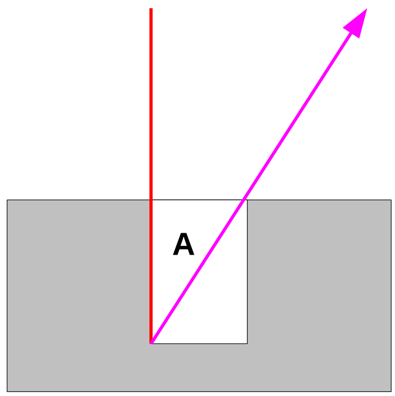
With no part in place, the laser beam should reflect off of the baseline and make a horizontal line near the bottom of the image. Rotate the camera or the laser in the plane such that this line is nearly horizontal in the image. First rotate the laser so that the laser line is perpendicular to the “gray plane”, and then rotate the camera around its optical axis to make the reflected laser line horizontal. The closer you get the reflected line to be horizontal (or vertical, as noted above), the better accuracy you will get. It is easy to get an alignment within a few degrees “by hand”, and this can give acceptable accuracy.

The distances from the laser and camera to the part are set by the focal length of the lens and laser and the physical constraints of your setup. Longer working distances might reduce some distortions (see **Lens Selection**), but will also make the laser line dimmer.

Height Resolution and Laser Line Visibility

Increasing angle A (shown as the green arc in the previous drawing) increases the resolution of the height measurements – small changes in height are “amplified” more by larger angles. However, increasing the laser-camera angle also increase the number of points where the camera can’t see the reflected laser beam because the beam is in a hole or concavity.

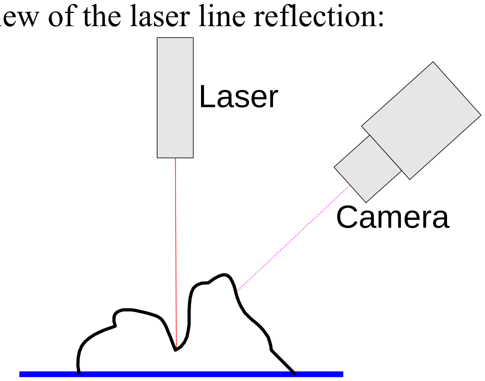
You can set angle A based on your system’s geometry and the ratio of the width and height of holes in the part. In this drawing, the red laser beam (“laser above”) enters a hole in the part. For the reflected beam (drawn in magenta) to be visible to the camera, the camera must not be at an angle greater than A. A equals the arctangent of (hole width / hole depth).



In practice we do this experimentally. We set the camera at some angle, typically about A = 45 degrees and then try parts to make sure that the height resolution and laser line visibility are acceptable, adjusting the camera position and angle as necessary.

Concavities

With any angle A greater than 0, there could be narrow holes or concavities in the parts that block the camera’s view of the laser line reflection:

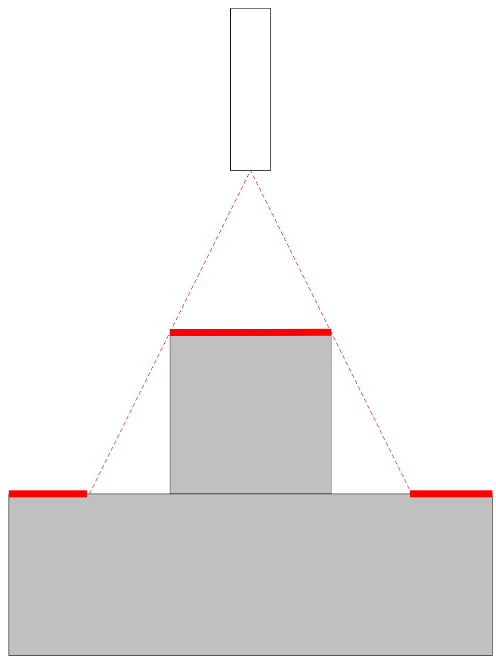


Setting angle A to 0 to see down a borehole, for example, means no height amplification so no measurement. To measure down a borehole, use a different type of depth gauges.

Fan Beam Effect

The “Fan Beam Effect” also prevents the camera from seeing the laser beam, but in this case the beam is blocked along the profile line rather than blocking the reflected beam to the camera at one or more profile points.

We assumed that the laser line is a “sheet” of light but, in fact, the light is fan shaped, expanding with distance from the laser. In this drawing, the line of laser light is in the plane of the page, with the laser source at the top.



Higher points on an object can block the fan beam, in effect shadowing lower points so they can’t be seen by the camera. In this diagram the higher area intercepts the laser’s fan beam so the laser light doesn’t reach the two areas on the lower area – they are shadowed by the upper area. The surfaces illuminated by the laser light are marked with a thick red line.

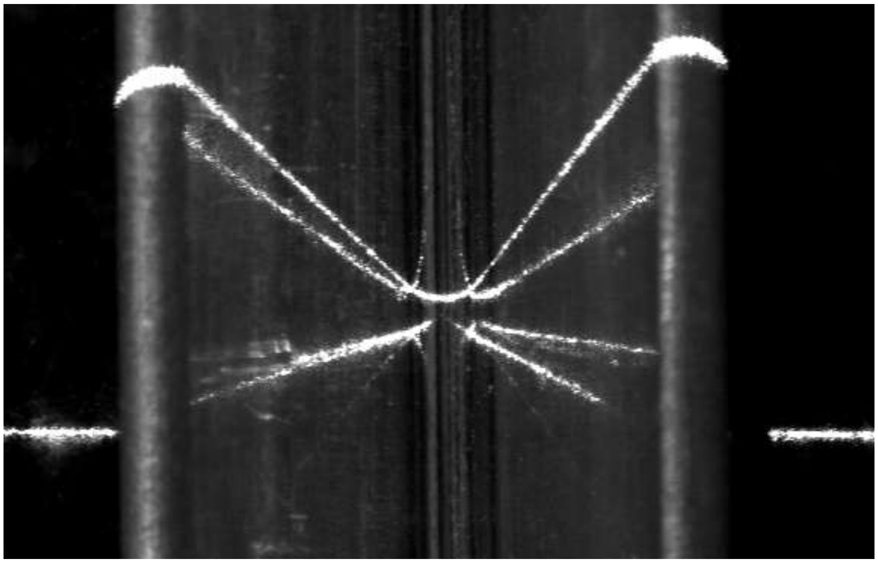
Moving the laser away from the object reduces this effect but also spreads the laser line and so reduces the amount of light reflected into the camera. This “fan beam effect” and the similar problem of concavities or holes (discussed above) means height profiles can have gaps in them and 3D surface maps will therefore have holes in them.

Laser Height deals with gaps by not reporting a height measurement at a gap location. Holes in surface maps could be “filled” from surrounding height measurements. If you need data in these gaps or holes, consider using multiple laser and camera setups but with the lasers and cameras positioned to view different part areas.

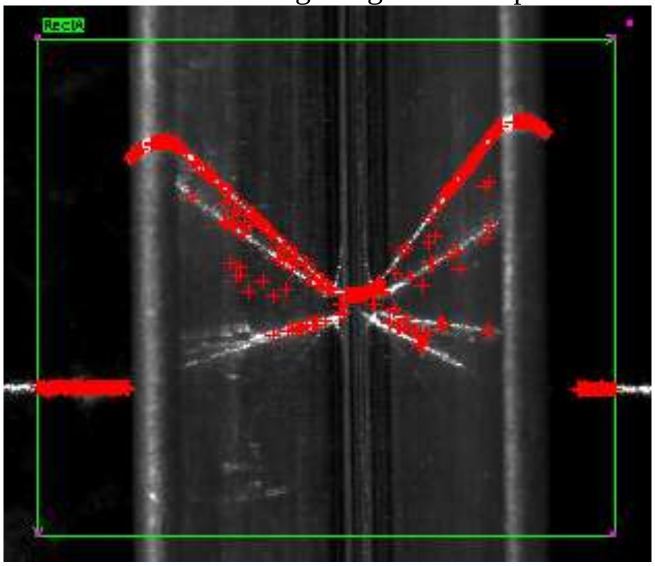
Secondary Reflections

Metal and high-gloss objects could reflect the laser line onto another part of the object, thus producing multiple, secondary reflections into the camera. Try to set up your laser and camera to suppress these secondary reflections, as the Laser Height algorithm finds only one bright point per image column (or row if you are using a vertical baseline).

Here is an image of a V shaped metal extrusion where the inside of the "V" causes secondary reflections of the laser line. We added some diffuse illumination so you can see the part:



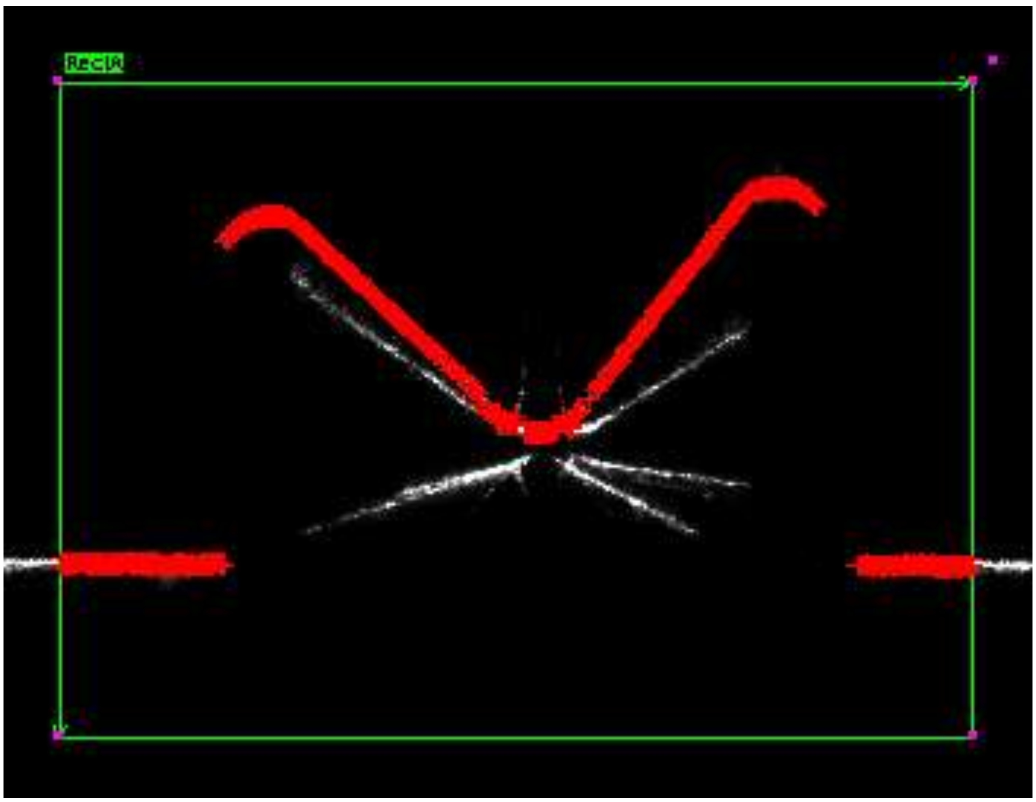
Here is what the Laser Points or Laser Height algorithms report:



Many points are incorrectly reported from secondary reflections, rather than along the primary laser line reflection – the top-most line in this case.

If secondary reflections cannot be prevented, you can sometimes get more of the correct measurement points by selecting the "find first" option in the Laser Points or Laser Height algorithms' ***edges*** parameter. Instead of finding the strongest edges (dark-to-light and light-to-dark for the two sides of the laser line), the algorithm finds the first edge that is above the ***min. strength*** edge strength parameter. As scanning for a horizontal laser line is done from top to bottom, we will pick up the top-most or "first" points – the ones we want in this example. If we were using a vertical laser line, this option would pick up the first points scanning from left to right.

Here is the result from Laser Points with "find first" rather than "find maximum" enabled, the diffuse illumination removed, and the threshold adjusted:



Nearly all of the desired bright points (heights) are now found.

This feature allows measurement when there are reflections of the laser line, if the points of interest are "first" in the direction of scan – top-most on a horizontal laser line and left-most on a vertical laser line.

Summary of Optical and Physical Setup

Following is a summary of the steps required for optical and physical setup of most laser height measuring systems. The reasons and details are given in previous sections.

- Polished, high gloss or specular objects might not provide enough reflected laser line light into the camera. If you are not sure, first do an experiment to see if you get enough light into the camera. See if a stronger laser helps.

- Select a line light laser with enough power to reflect the line off of the object being measured and into the camera. Pick a laser color that matches the color of the object to increase the strength of the reflection off of the part.

- Select a lens (using LensHelp) with a field of view as wide as the height profile and as high as the maximum displacement of the reflected laser line at the highest point on the object. Use the longest focal length lens possible, to reduce optical distortion. Use a telecentric lens when high accuracy measurements are required.

- If the measurement system can't be enclosed to block ambient illumination, use a bandpass filter on the lens that matches the laser light wavelength. This will "reject" most of the ambient illumination while passing the laser line reflections and so increase the contrast of the image bright points used for measurement.

- Select a camera with sufficient pixels to give the required resolution along the profile (in X if a horizontal baseline) and in height (in Y if a horizontal baseline). Sub-pixel interpolation can give slightly better height resolution than the number of pixels in a column, so a 768 pixel column has a resolution of about 1000.

- Mount the laser and camera in the same plane and rotate (in yaw and roll) the laser line so that it is perpendicular to this plane and perpendicular to the object and across the object. Rotate the camera around its optical axis (roll) so that the reflection of the laser line is nearly horizontal or vertical in the image. Rotate the camera (in pitch) so that the optical axis is pointing at about the center height of the object being inspected.

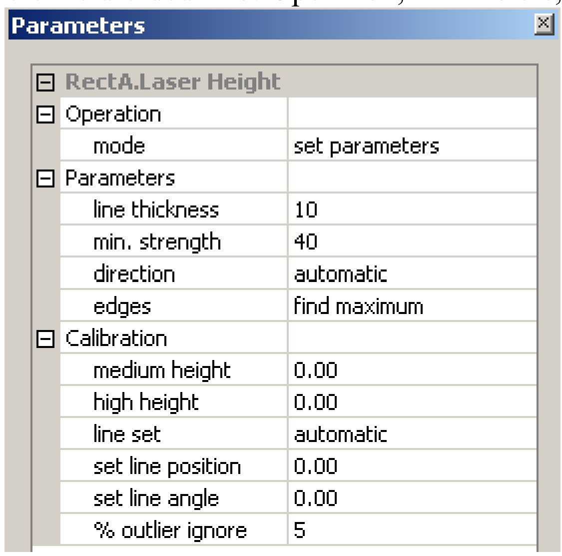
- Set the angle between the laser center ray and the camera's optical axis (angle A in the above drawings) to be about 45 degrees. Larger angles will amplify the deflection of the laser line with height, but will also cause the view of more points on the profile to be blocked by holes or concavities in the object. Experiment with the setting this angle (angle A) until you balance the required discrimination of heights and views into holes or concavities.

- If possible, adjust the setup to prevent secondary reflections, sometimes called "self-reflections". These occur on metal or high gloss object where the object reflects the laser line onto another part of the object.

Laser Height Parameters and Outputs

NOTE: The ***line start*** and ***line end*** parameters are not in the current (7.1.2.0) version of Sherlock, and the angle "readout" in "light-camera alignment" ***mode*** is also missing.

Laser Height's parameters are divided into: Operation, Parameters, and Calibration:



Operation Parameters

The ***mode*** parameter sets the mode of operation of the Laser tools. Choices are:

- Set parameters. Laser Height does not process image information, so you can set parameters without "learning" height calibrations
- Light-camera alignment Use to focus the line of light and camera. Use to align the line of light and the camera by rotating the camera so that the line of light is nearly vertical or horizontal in the measurement ROI.
- Set baseline Calibrate using the baseline
- Set medium Calibrate using the shorter of two calibration objects
- Set high Calibrate using the taller of two calibration objects
- Run Run Laser Height to get calibrated height values

Parameters (general)

These parameters specify the properties of the imaged laser line.

The ***line thickness*** parameter is the approximate thickness of the reflected laser line when at its thinnest. The laser and camera should be focused so that the thinnest line is when the line is reflected off an object with a height in approximately the middle of the height range. You can measure line thickness using the Laser Caliper algorithm or use the "readout" when in "Light-camera Alignment" ***mode***. This is not a critical parameter, but should not be much larger than the thinnest reflected line.

min. strength is the minimum change in point edge strength need to detect a bright point in the image. You should adjust this parameter so that desired bright points (reflections of the laser line off of the object being inspected) are detected reliably but noise or secondary reflection points are not detected.

Set ***direction*** to specify the direction of the laser line in the image. Your options are:
- horizontal	The laser line is horizontal (as in the above image)
- vertical	The laser line is vertical in the image
- automatic	The algorithm finds the direction (horizontal or vertical) of the laser line in the image. "automatic" is the default but is the slowest option as the image must be searched to determine the line direction. We recommend not using "automatic".

Set the ***edges*** parameter to:
- find maximum	Maximum contrast edges above ***min. strength*** are found
- find first	First edges with contrast more than ***min. strength*** are found

The "find first" option can be used to prevent secondary reflections off of the object from being used as measurement points.

Calibration Parameters

These parameters are used to calibrate Laser Height.

Set the ***medium height*** parameter to the height of the shorter calibration object, for example 0.25 inches. Set the ***high height*** parameter to the height of the taller calibration object, for example 0.75 inches.

The ***line set*** parameter selects how a calibration line is to be found:
- automatic	Laser Height automatically fits a calibration line to the bright points in the image. The ***line start, line end*** and ***% outlier ignore*** parameters select the set of points used and reject the percent of points that differ most from the majority of the line points.
- manual	Use ***set line position*** and ***set line angle*** to set the calibration line.

When ***line set*** is "manual", the ***set line position*** and ***set line angle*** parameters are used to manually set the position and angle of a calibration line. When ***mode*** is "light-camera alignment", set line position is used to move the calibration line over the laser line so camera rotation can be set.

When "***line set*** is "automatic", ***% outlier ignore*** is the percent of points to ignore in the laser calibration line because they deviate from the majority of the laser line points. For an essentially straight line, set this to 0 or a few percent. The larger the **% outlier ignore**, the slower this algorithm runs.

When ***line set*** is "automatic", the ***line start*** and ***line end*** parameters set the section of the line to use for automatic fitting of a calibration line.

Laser Height Outputs

“valid” – True if one or more bright points (points with edge strengths over min. strength) were found.

“line strength” – Average strength of the edges in the reflected laser line.

“heights” – Array of values for the computed heights. Height values are in whatever units you used for calibration.

“baseline” – A Sherlock line indicating the baseline (lowest or reference point) of the height measurement.

“points used” – Array of point values, indicating which bright points in the image were used. For horizontal baselines, the X values in this array will be integers. For a vertical baseline, the Y values in this array will be integers. For example, with a horizontal baseline the X values might be: 0, 1, 2, 7, 8… Missing index values indicate columns (or rows if a vertical baseline) where a bright point couldn’t be found. Because “point used” values are used to indicate which points were used and which are missing, you should not apply calibration to Laser Height outputs. However, as discussed above, you might find that optical “restoration” is useful.

Laser Height Algorithm Setup

With the optical and physical setup done, you are ready to apply Laser Height to measure object heights.

Remember: The Laser Height assumes that:

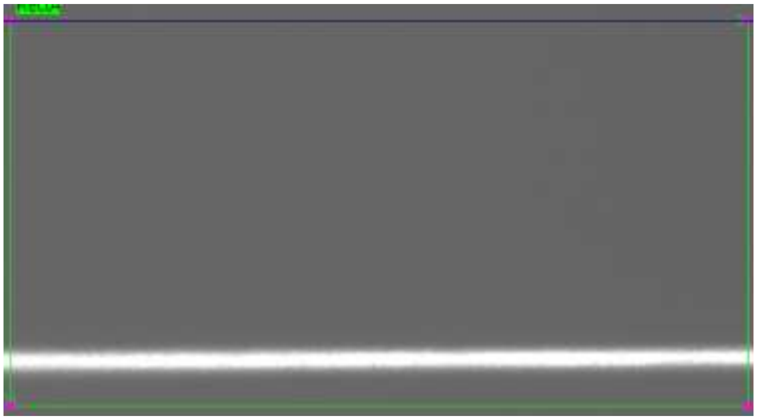
- The laser line reflections are bright points against a dark background
- There is a single point of reflected light in each column or row (but see **Secondary Reflections**)
- The laser line reflection from the baseline (a reference surface) is nearly horizontal or vertical in the image and, with the part in place, the reflected laser line points are displaced vertically or horizontally respectively, not diagonally. To get this, both camera and laser must be in the same plane. You will rotate the laser around its "roll" axis to be perpendicular to this plane. As part of setup you will rotate the camera around its roll axis to make the reflected laser line appear horizontal (or vertical) and adjust its yaw angle to cover the height range.

For setup you will need a baseline – the lowest height reference surface – and two objects of known height. We recommend using two calibrated gauge blocks. These blocks are usually made out of steel and so have poor off-axis reflection resulting in dim reflected points in the image (see **What Types of Objects** section). To improve the off-axis reflection of gauge blocks, you could anodize, paint or etch the top surface of the blocks. These treatments, unfortunately, decrease the accuracy of the gauge blocks.

Alignment

1. Create a rectangular ROI that includes baseline reflected points and points reflected from the highest point on the object being inspected. You may need to adjust the camera angle, A, and rotation the camera around its pitch axis to get the full range of heights in the image (and in the ROI).

2. Select the Laser Height algorithm for this ROI and take an image of the baseline, that is of the lowest, reference surface with no objects in place:



The top side of the ROI (or left side if you are using a vertical laser line) is blue because there is a calibration line there. You will change this line position during camera alignment and calibration.

3. Laser Height starts with the ***mode*** parameter set to “set parameters”. In this mode, Laser Height is not processing data, so you can set parameters without unwanted effects. While you can change most parameters at any time, we suggest you now set the “constant” parameters (ones with fixed values):

- Set ***line thickness*** to the approximate thickness of the reflected laser line when at its thinnest point. If you have followed the **Optical Setup** instruction, the thinnest point will be in the middle of the object height as that is where the camera is focused. You can measure line thickness using the Laser Caliper algorithm or get it from the annotations in the “light-camera alignment” ***mode***. This is not a critical parameter, but should not be much larger than the line thickness. If you are unsure, go for smaller values and see how they do.

- Set ***direction*** to “horizontal” or “vertical”, which ever setting is appropriate. The default setting, “automatic”, is significantly slower because Laser Height has to search for the laser line image direction.

- Set ***edges*** to “find maximum” (The default) for a normal laser line image or to “find first” if there are secondary reflections (see **Secondary Reflections** section) and the primary reflection (the bright points you want) are the top-most or left-most points in the image of a horizontal or vertical, respectively, laser line.

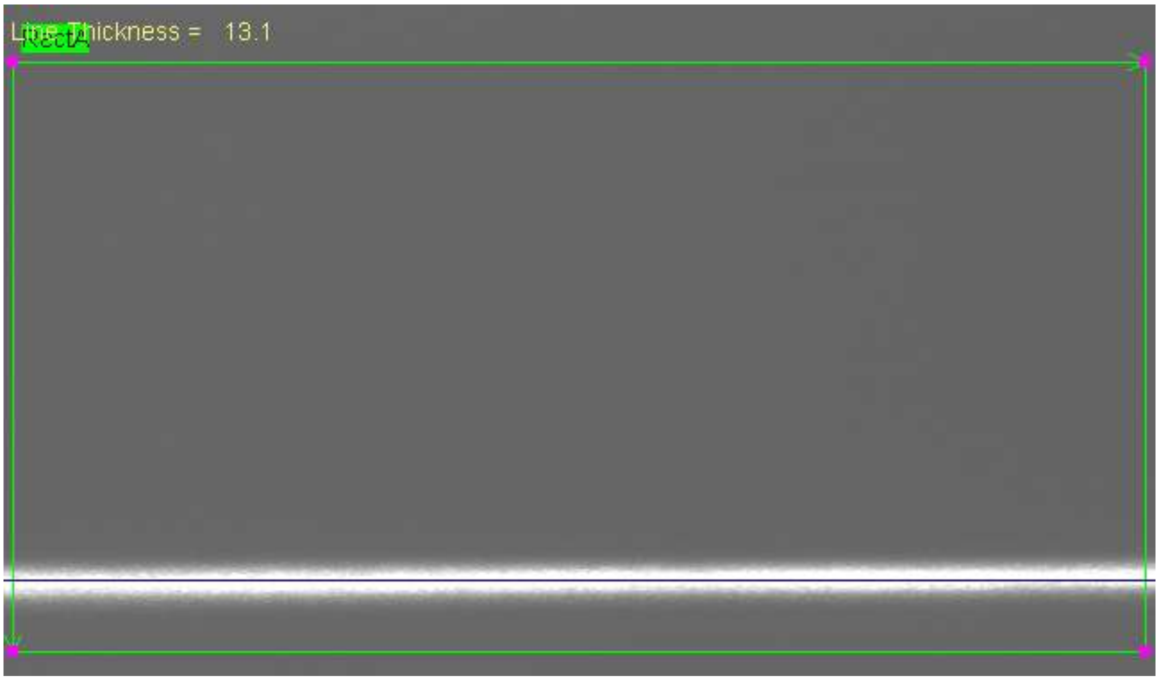
- Set the values of ***medium height*** and ***high height*** to the height of your smaller and larger calibration (gauge) block, respectively. These heights are dimensionless and so can be in any units, for example 0.25 and 0.75 inches. No mixed units, such as feet and inches!

4. In this step we are going to set the roll angle of the camera (that is, around its optical axis) such that the laser line reflection from the baseline appears horizontal (or vertical), so height changes cause bright points (reflections off of the object) to move up or left (if a vertical laser line).

Set ***mode*** to “light-camera alignment”. Height runs once and the blue calibration line jumps to the bottom (or right, if a vertical laser line) of the ROI. Snap an image of the laser line reflecting from the baseline, if you don’t already have one. Adjust ***min. strength*** until snapping an image gives reasonable values in the line thickness and line angle “readouts” in the upper, left of the image.

Use ***set line position*** to move the blue calibration on top of the laser line. Compare the angle of the laser line with the horizontal or vertical calibration line and look at the “readout” of the line angle in the upper, left corner of the image. Now rotate the camera around its roll axis to reduce the angle between these two lines or, equivalently, to move the line angle towards 0 (if horizontal laser line) or 90 degrees (if a vertical laser line). You have to repeatedly snap single images, compare, rotate,… to adjust the camera's roll angle, as there is currently no mechanism in Sherlock for plug-ins to call for image acquisition.

The average thickness of the laser line and its angle are displayed in the upper, left corner of the image. You can use the average thickness to set the ***line thickness*** parameter:



Calibration

The next three steps use a baseline and two known heights (usually gauge or calibration blocks) to calibrate Laser Height in any units, because the calibration is dimensionless. In all three steps you will align the blue calibration line with the image of the laser line reflected off of the baseline or one of the two known heights. The alignment of the calibration line and laser line can be "automatic" or "manual", as specified by the ***line set*** parameter.

When ***line set*** is "automatic" Laser Height will fit the calibration line to the laser line for you. You must set the ***line start*** and ***line end*** parameters to select a segment of the laser line to use. Set the segment to be as large as possible but without including any "bumps" or "gaps" in the laser line. Within that segment the ***% outlier ignore*** parameter rejects the specified percentage of reflected laser line points whose position differs most from the majority of the points in this laser line. If no points differ significantly, set ***% outlier ignore*** to 0.

When ***line set*** is “manual”, you will adjust the ***set line position*** and ***set line angle*** parameters to align the calibration line with the points of the laser line. The ***line start***, ***line end***, and ***% outlier ignore*** parameters are not used.

5. Take a picture of the laser line reflecting off of the baseline, for example a mounting surface or conveyer belt, with no objects present. Select “manual” or “automatic” for ***line set***. If there are gaps, bumps, or significant roughness in the baseline, using “manual” gives better results. Or increase ***% outlier ignore*** and use “automatic” to see how that works.

Switch ***mode*** to “set baseline”. If you are using “automatic” ***line set***, the blue calibration line should snap to the center of the laser line. If it doesn’t try adjusting ***min. strength***, ***line start***, ***line end***, and ***% outlier ignore*** to get the correct line. If you are using “manual” ***line set***, adjust ***set line position*** and ***set line angle*** to align the calibration line with the baseline.

Switch ***mode*** back to “set parameters”. Laser Height has now “learned” the baseline calibration – it remembers the last parameters that were manually or automatically set for alignment of the calibration line with the baseline.

6. Place the shorter calibration block under the laser line and take a picture. Switch ***mode*** to “set medium line” as, the shorter calibration block has a height that is between (medium) the baseline and the high height. As with the baseline, select “manual” or “automatic” for ***line set*** and adjust appropriate parameters to align the blue calibration line with the center of the laser line (bright points in image).

Switch ***mode*** back to “set parameters”. Laser Height has now “learned” the medium height calibration.

7. Place the taller calibration block under the laser line and take a picture. Switch ***mode*** to “set high line”. As with the baseline, select “manual” or “automatic” for ***line set*** and adjust appropriate parameters to align the blue calibration line with the center of the laser line (bright points in image).

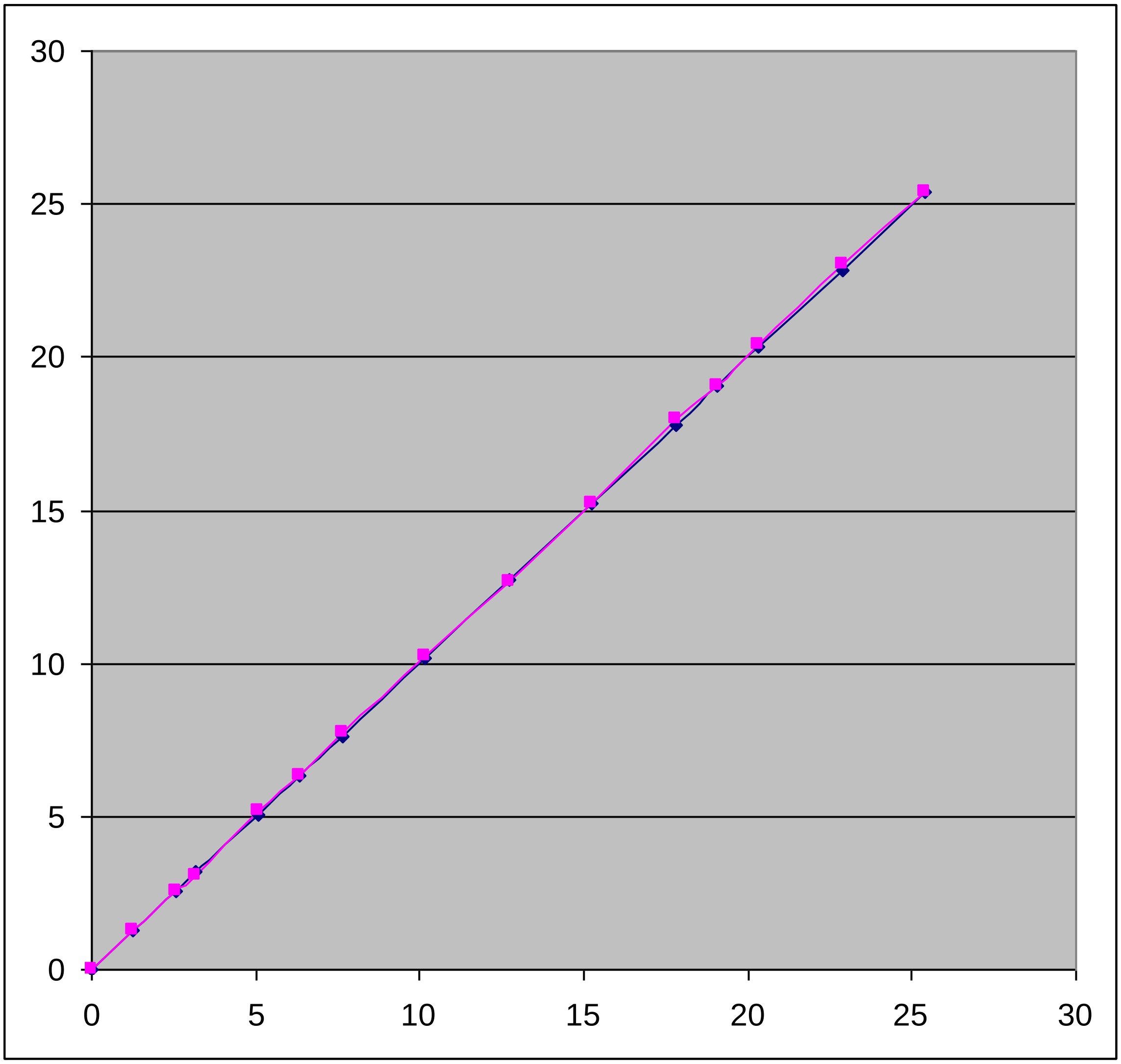
Switch ***mode*** back to “set parameters”. Laser Height has now “learned” the high height calibration.

Running Laser Height

8. Switch mode to “run” and Laser Height will process the bright points in the ROI into output height values each time the algorithm is run by Sherlock. Adjust ***min. strength*** and ***line thickness*** for best results.

Improving Accuracy

Laser Height's accuracy depends on many factors, so a specification of accuracy and repeatability is not possible. To give you an idea of accuracy, here are results from a laser system that has a 33 mm field of view along the profile, a 25.4 mm height range, uses a 25 mm lens and a 640 x 480 camera (JAI CV-A11) at A = 45 degrees, and is calibrated using gauge blocks covered with paper (adds variation to gauge block heights).



Real height is on the X axis and reported height is on the Y axis (both in mm). The blue line is the ideal response line, Y = X. The magenta curve connects the values reported by Laser Height for various heights of gauge blocks. The average error across all measures is 0.045 mm, suggesting a resolution of 550 which is slightly better than the 480 pixels in a camera column. The average error could be reduced by not calibrating with paper-covered gauge blocks!

Here are some suggestions for improving accuracy:

Use a Telecentric Lens

A telecentric lens only accepts light rays in a column, so there is little optical or perspective distortion. Unfortunately, the field of view of a true telecentric lens is thereby limited to the diameter of the first (front) optical element in the lens. If you can use a telecentric lens, it is an easy (but not cheap) way to immediately improve height measurement accuracy.

Object Vibration and Movement

Control vibration and part movement so the part doesn't shift up or down in height. If this is not possible, use a reference height to measure the gross movement of the part and subtract it from the height measures. For example, an object on a conveyer belt might have some height "ripple" as the belt moves. To compensate for this, measure the height of the belt at one edge and subtract this varying height from the object height measures. Better yet, measure the belt height at both edges and use a height line fit to these two points to get values to subtract from object heights. This helps remove warping or tilt in the belt.

Better Depth of Field

"Depth of Field" is a measure of the distance, in this case the height, over which there is good focus. As mentioned, narrower laser lines and larger depth of field for the camera lens gives better accuracy. The laser depth of field might be improved by moving the laser away from the part, but at the expense of less light "signal" into the camera. You can stop down (close the aperture) of the camera to improve depth of field, but again at the expense of less light "signal" into the camera. The signal can be improved in both cases by using a brighter (higher wattage) laser.

Regular Re-Calibration

The electrical and optical components in a Laser Height system have very little change over time. If the positions of the electrical and optical components could shift, consider a regular schedule of re-calibration. This might happen, for example, in high vibration situations or where the operator of the system could bump the components.

You could put an object with a known height at one or both ends of the profile line and use that as a reference height to detect changes in the positions of the electrical and optical components.

Improving Accuracy on Lager Height Ranges

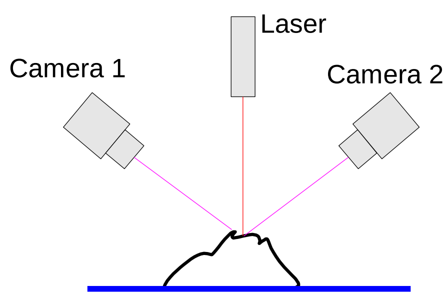
Laser Height's algorithm to convert point positions on the sensor (variable u in a previous drawing) to heights is limited to a second-order (parabolic) correction, as you might expect from the use of three calibration points. This correction is usually sufficient for limited height ranges; say up to 10 cm (4 inches). Here are two methods to improve accuracy when there is a large height range.

You could use multiple ROIs, "stacked" on top of each other, and calibrate height within each ROI. Then the conversion from point position to height becomes piecewise parabolic. That is, each ROI sees only a small range of pixel positions that can accurately be converted to heights by a parabolic equation.

You could use Laser Points instead of Laser Height and build a calibration look-up table (LUT). Use gauge blocks or other objects that span the range of height to be measured. Record the pixel value for each height in a table and develop methods to interpolate between table values. The pixel positions are then used to search the table and the interpolated height is output. If this method is necessary, contact Teledyne DALSA for help.

Building 3D Surface Maps

Individual height profiles across an object can be joined to build a 3D surface map, sometimes called a topographic map. One way to do this is to use the height profiles points as vertices in a triangular mesh. The method used will have to deal with missing points due to obstructions or dim reflection signals. Multiple cameras can be used to reduce the number of obscured points:



In this drawing, Camera 1's view of the laser line is obscured by a "peak" in the object, and so it records a "can't see" in the height values. Camera 2, however, can see the laser line and its values can be combined with Camera 1's values to give a surface map with fewer "holes".

The current release of Sherlock does not provide an algorithm for building 3D surface maps, but this can be done using the Laser Height data and graphics programs. Again, contact Teledyne DALSA if this is a requirement, and we will see what help we can give.