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MSc. ROBOTICS AND CONTROL SYSTEMS

(MRE002A) PERCEPTION

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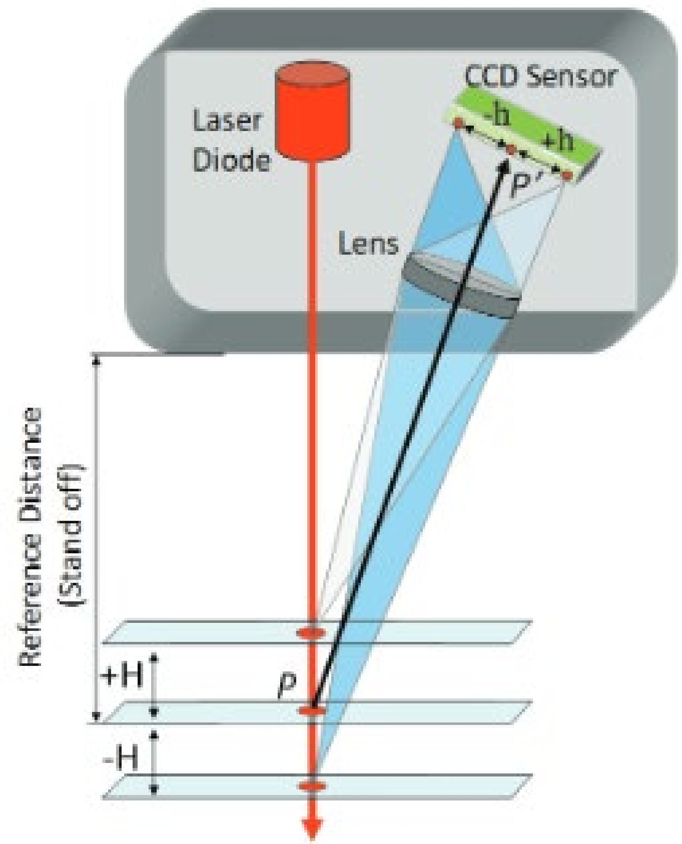
LASER TRIANGULATION

LASER TRIANGULATION

Laser triangulation system?

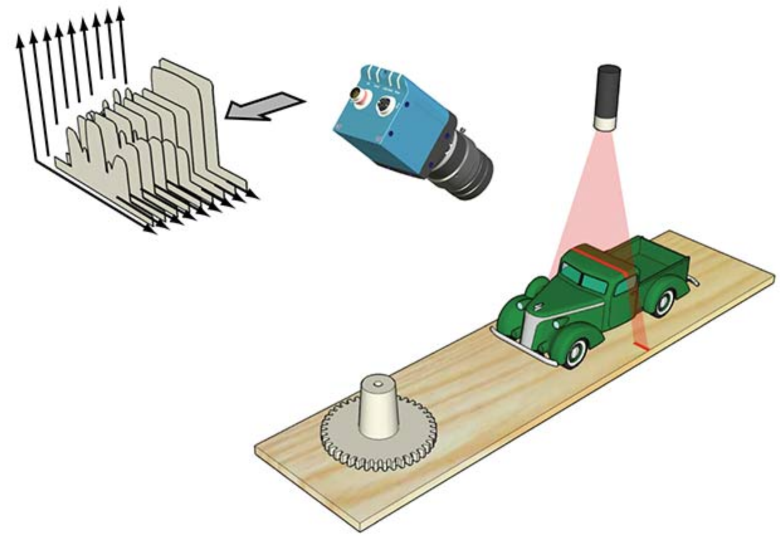
- Machine vision systems based on 3D triangulation are employed in a range of industries from automotive and electronics manufacturing to lumber mills.

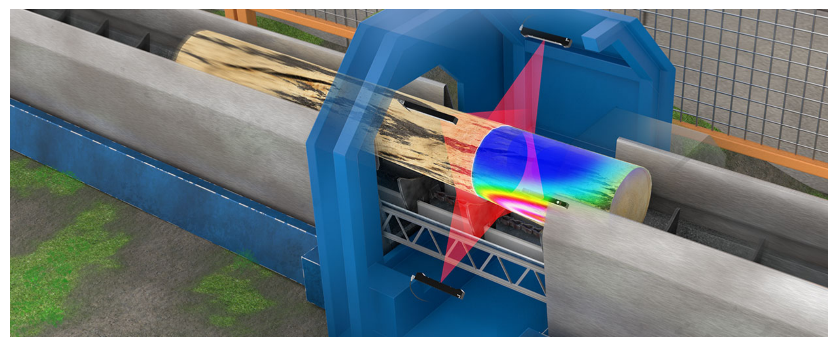
- While the basic concept of measurement using triangulation is simple, there are several important details must be addressed when implementing such systems.



LASER TRIANGULATION

- There are four main components of a 3D triangulation system:
  - The camera,
  - The line projector that is typically laser-based,
  - A mechanism that moves the object or camera/laser system through the field of view of the imaging system and
  - Software to process the captured image and accurately translate pixel offsets to height differences.





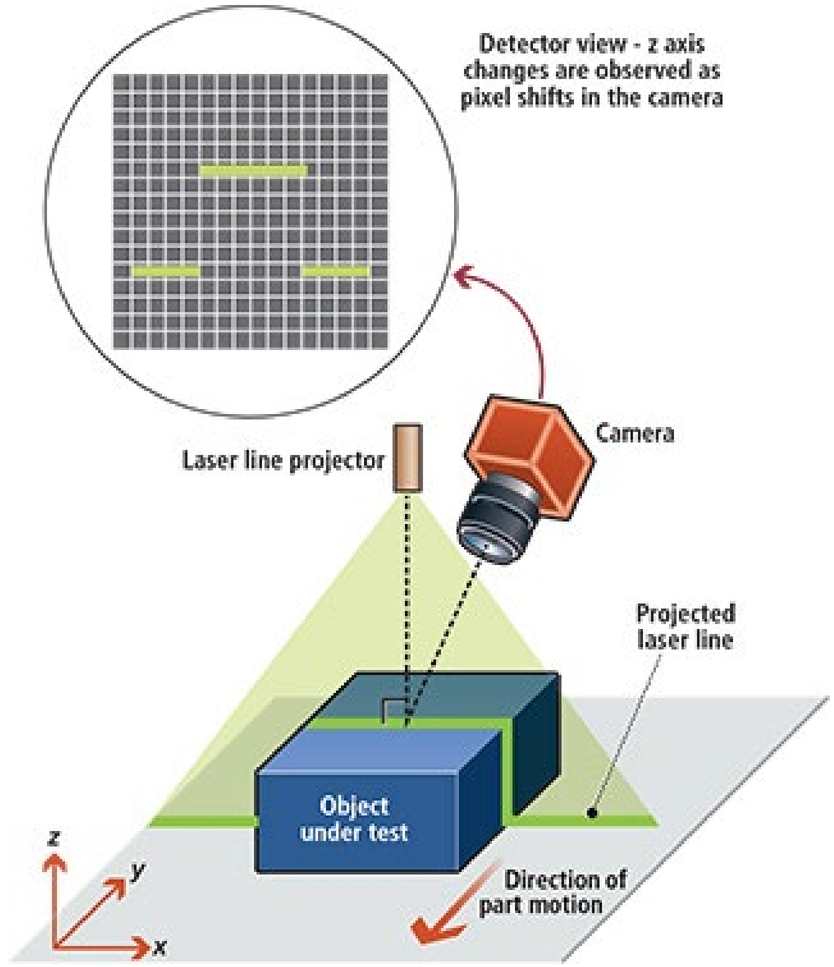
LASER TRIANGULATION

Laser triangulation system?

- Laser-based 3D triangulation systems configuration
- Laser line parameters

Principle

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

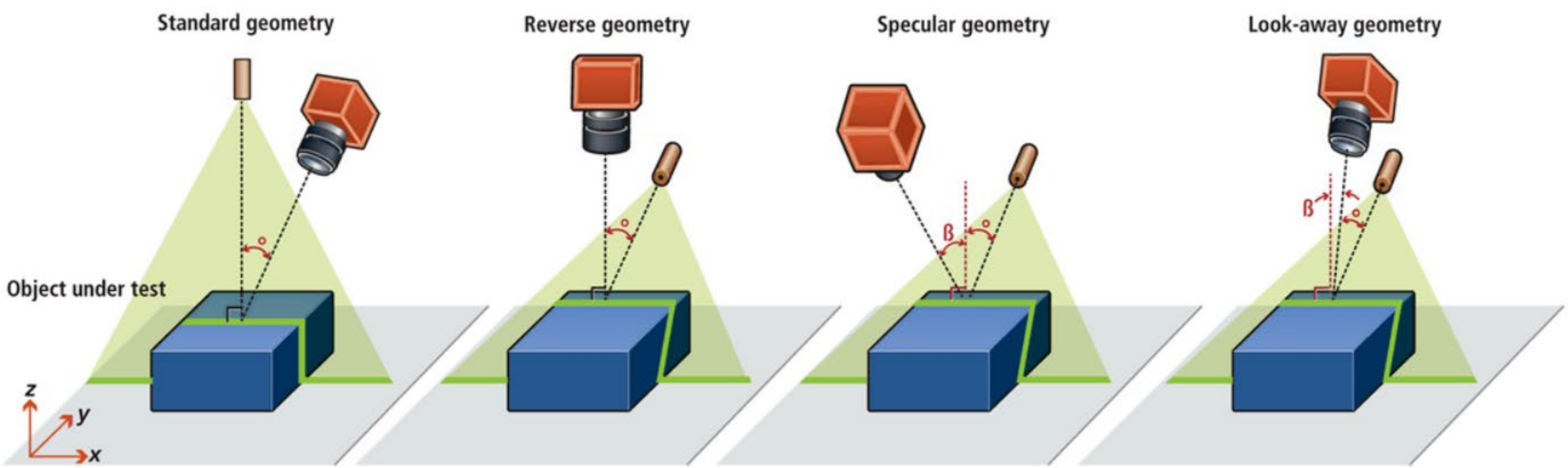


LASER TRIANGULATION

Configurations:

- Laser line projection systems can be implemented in several different ways, each of which has its own unique characteristics, advantages and disadvantages.

- Four of the most common geometries are shown in Figure

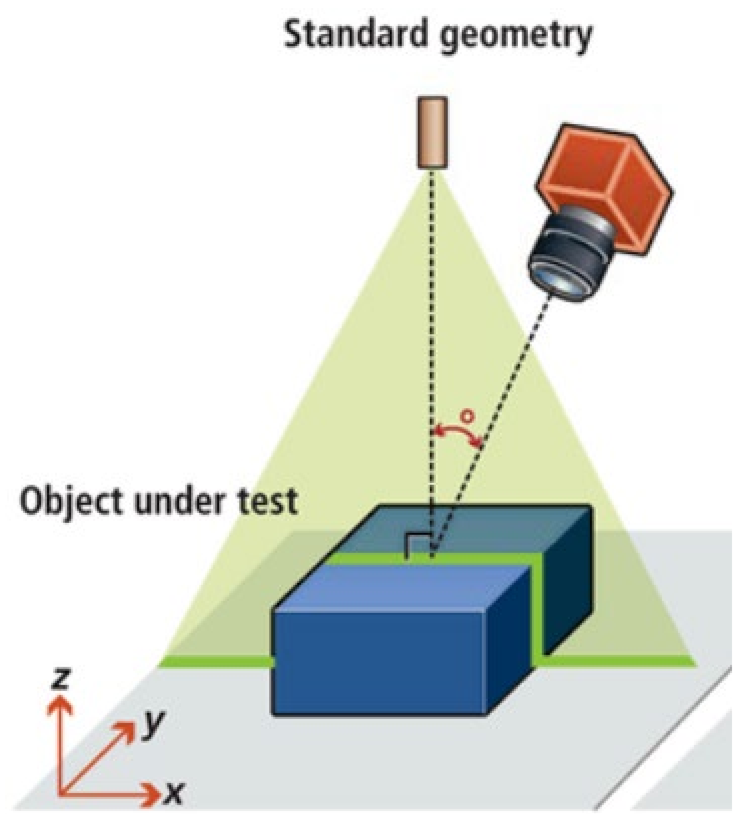


CONFIGURATIONS

Configurations: Standard Geometry

- Is the most commonly employed method,
- The laser line is projected perpendicular to the nominal measurement (x, y) plane.

The most important characteristic of this configuration is that height variations in the object along the projected line do not produce a change in the line's y coordinate values



CONFIGURATIONS

DOF and MAGNIFICATION

- The camera views the object from an angle. This increases the depth of field it must accommodate to maintain focus as object height varies.
- The lens experiences greater magnification as object height (and hence object distance from the lens) changes. Thus, a test object must be calibrated to derive accurate measurement results from the system.

OCCLUSIONS and RESOLUTION

- Specifically, whenever the camera views the object from anything other than an angle perpendicular to the inspection surface, there will be some parts of the line which are blocked or occluded from the camera's view since no object is completely flat.
- Inherent design tradeoff, because, while measurement height resolution increases for the standard geometry as the camera angle increases, so does the potential for occlusion.

CONFIGURATIONS

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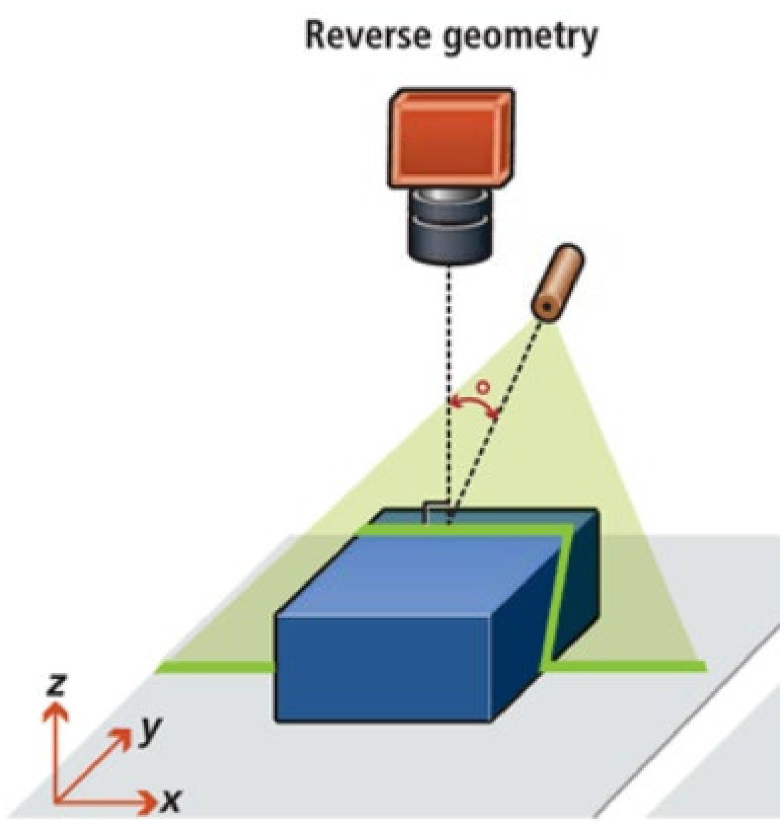
Configurations: Reverse Geometry

- Switching the positions of laser source and camera produces the reverse geometry.

Change in part height does cause a change in the line's y coordinate, making it more complex to interpret results.

This setup is generally most useful with planar objects



CONFIGURATIONS

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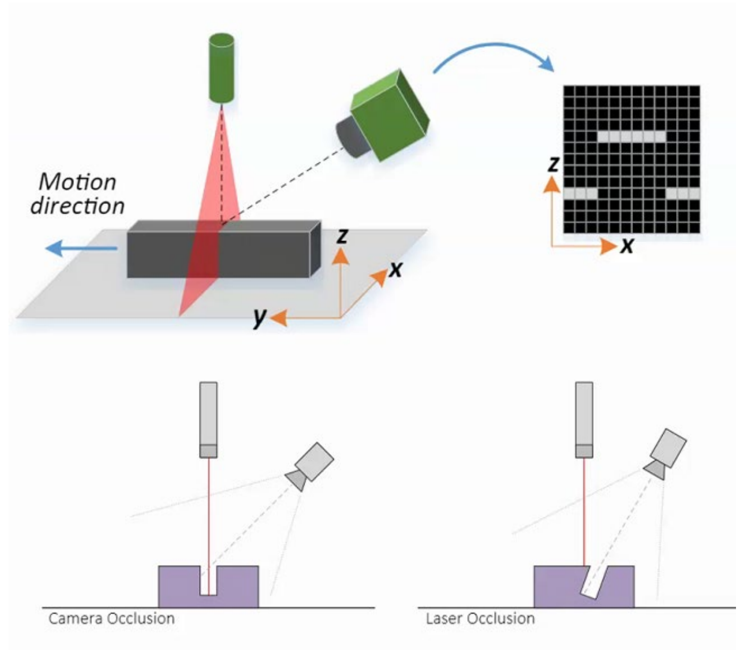
OCCLUSIONS and RESOLUTION

- This setup offers increased height resolution over the standard configuration, since the oblique angle of laser illumination means a given change in object height produces a larger shift in the position of the laser line.

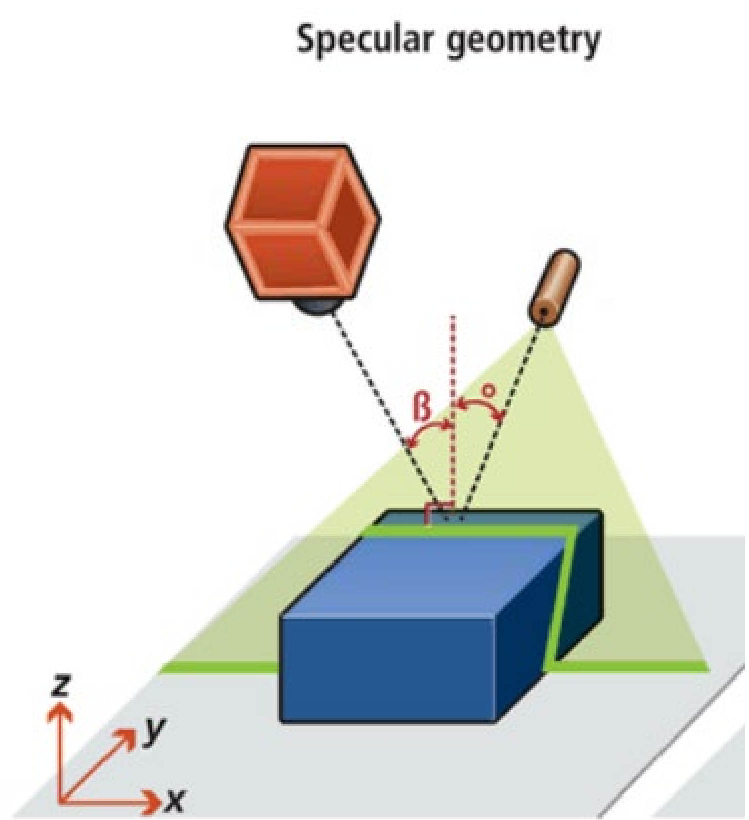
- Since the camera is normal to the measurement plane, there is no occlusion in this geometry.



CONFIGURATIONS

Configurations: Specular Geometry

- In specular geometry configurations, both the laser and camera are at similar, non-normal angles to the surface.
- Once again, in the specular geometry configuration, a change in part height causes a change in the line's y coordinate, making it more complex to interpret results.
- This setup is best used when imaging planar objects.



CONFIGURATIONS

RESOLUTION

- Having both oblique projection and viewing angles provides greater height resolution over either of the previously described configurations.

REFLECTIONS

- In this arrangement, it is possible for the camera to see specular, or near specular reflections, from the laser. This can cause measurement errors if these reflections produce saturation or blooming in the detector.

LIGHT INTENSTY

- Higher reflection could be used to increase signal levels from dark colored objects since dark objects reflects less light

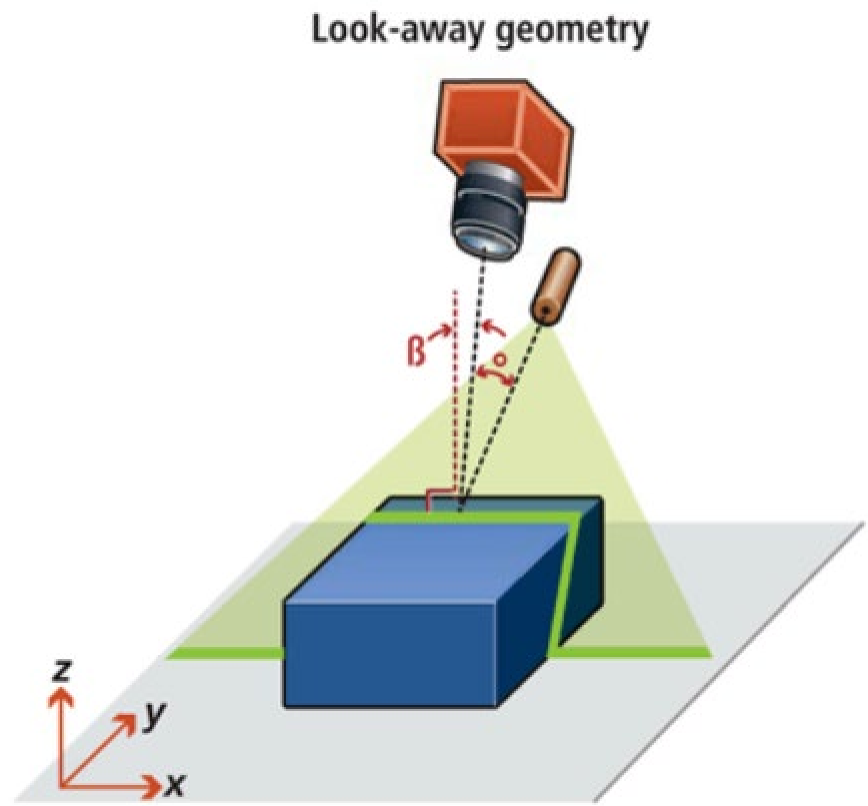
OCLUSIONS

- The oblique camera angle also leads to some occlusion.

CONFIGURATIONS

Configurations: Look Away

- Both the camera and laser projector are placed on the same side of the normal to the object surface.
- Reduces height resolution.
- Highly reflective surfaces.



CONFIGURATIONS

RESOLUTION

- This geometry reduces height resolution because the camera point of view is so similar to that of the projector.

REFLECTIONS

- This configuration dramatically reduces the chance of specular reflections, unless the object is highly textured.

OCCLUSIONS

- There is also some occlusion in this configuration

CONFIGURATIONS

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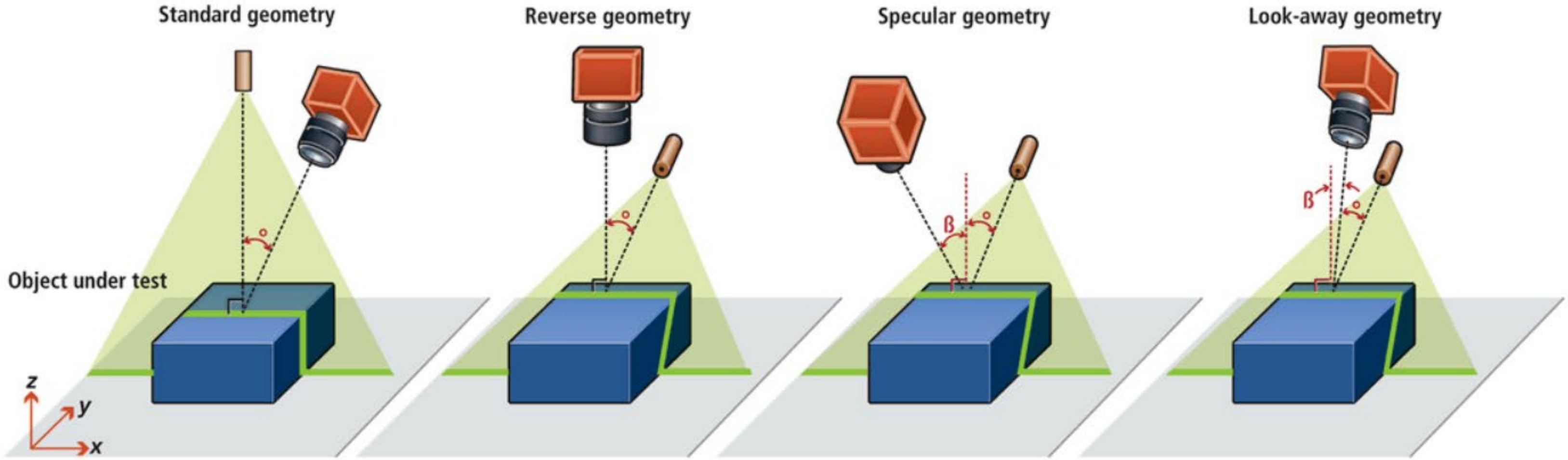

Table 1: Overview comparison of various triangulation geometries.

	Standard Geometry	Reverse Geometry	Specular Geometry	Look-Away Geometry
Main Advantage	Computationally simple	Increased height resolution	Useful with dark objects	Delivers highest measurement resolution
Main Limitation	Requires large lens depth of field	Computationally complex	Specular reflections can cause measurement errors	Some occlusion
Primary Use	General purpose	Applications requiring high accuracy	Dark colored or highly textured objects	Highly reflective objects (glass, metal, etc.)

LASER TRIANGULATION

LASER

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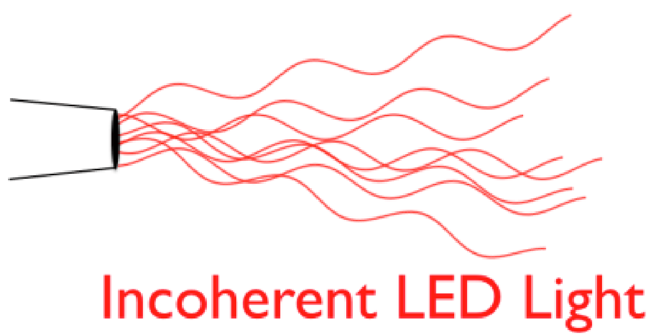
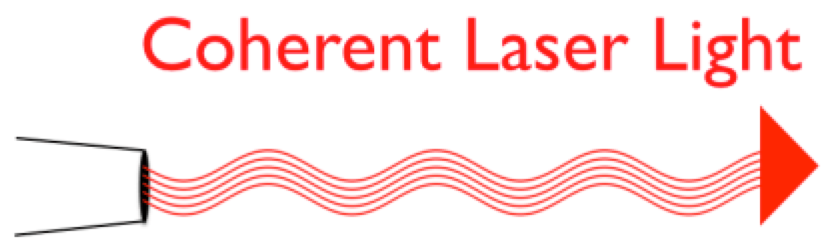
- A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.
- The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation".
- The first laser was built in 1960 by Theodore H. Maiman at Hughes Research Laboratories, based on theoretical work by Charles Hard Townes and Arthur Leonard Schawlow.



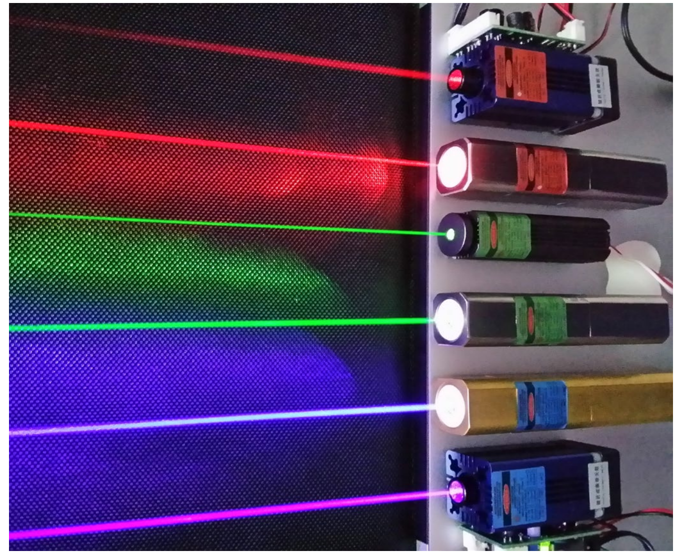


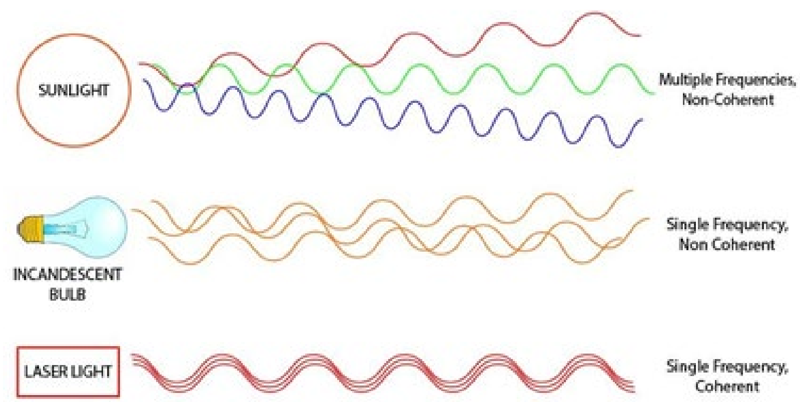
LASER

- A laser differs from other sources of light in that it emits light which is coherent.
  - Spatial coherence allows a laser to be focused to a tight spot, enabling applications such as laser cutting and lithography.
  - Spatial coherence also allows a laser beam to stay narrow over great distances (collimation), enabling applications such as laser pointers and lidar. Lasers can also have high temporal coherence, which allows them to emit light with a very narrow spectrum, i.e., they can emit a single color of light.
  - Alternatively, temporal coherence can be used to produce pulses of light with a broad spectrum but durations as short as a femtosecond ("ultrashort pulses").

LASER

- Knowing the parameters of the projected laser line is critical to creating and calibrating an accurate 3D triangulation system.
- All line projectors create a beam which is neither perfectly straight nor homogenous, and whose properties vary with distance from the projector.
- Only when these characteristics are understood and quantified can accurate measurements be obtained.



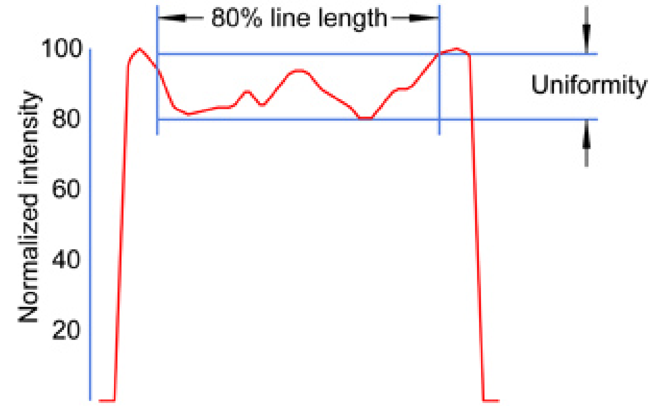


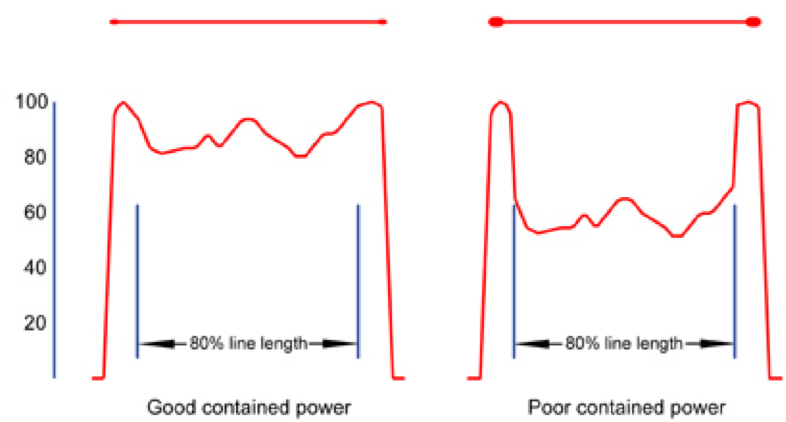
POWER UNIFORMITY

- One key parameter is the power uniformity of the line beam, fluctuations in which occur due to manufacturing variations and tolerance effects.

- These typically manifest themselves as intensity variations (particularly at the beam edges), non-flat top intensity profiles, and light scatter (from poorly matched or fabricated systems).

- Each of these effects can lead to measurement errors.

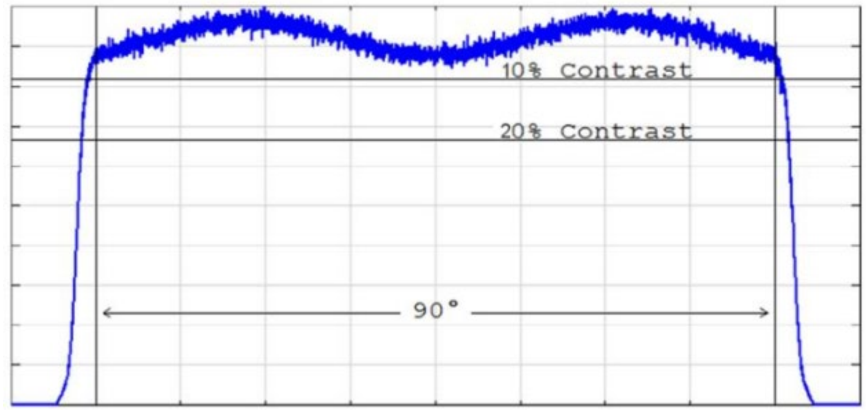




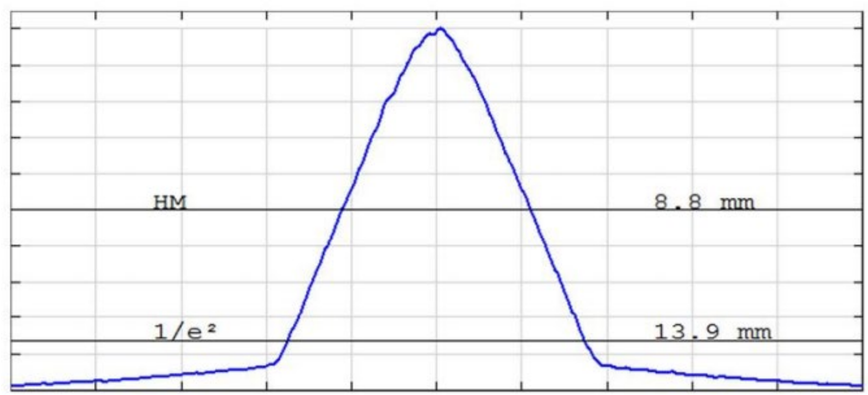
POWER UNIFORMITY

- Most laser line generator manufacturers specify line uniformity as the variation in the intensity profile from the average intensity value over a given region.

- Usually, this region is chosen to exclude the extremes of the beam edge, because this is where non-uniformities are typically most pronounced



Line length direction @2m



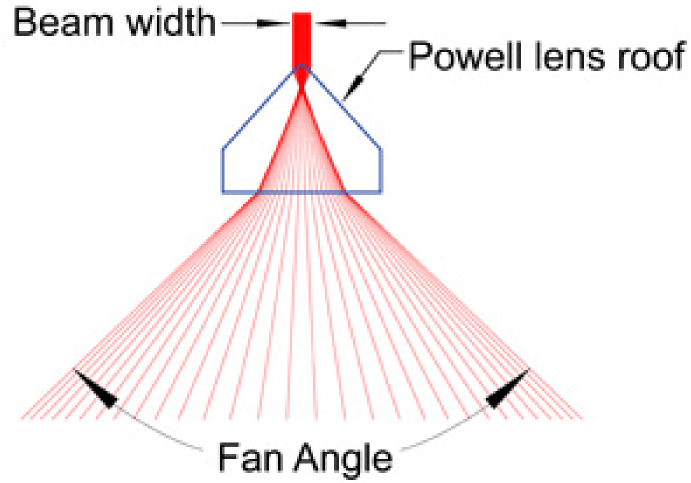
Line width direction @2m

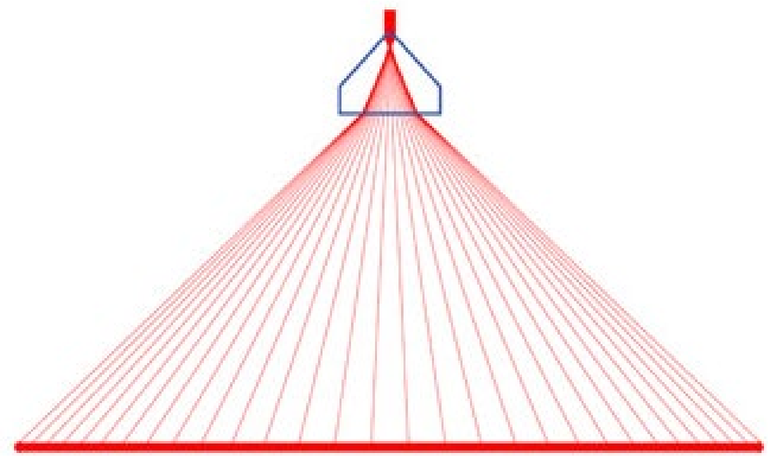
FAN ANGLE

The Powell lens resembles a round prism with a curved roof line. The lens is a laser line generator, stretching a narrow laser beam into a uniformly illuminated straight line

- The width of the Powell lens fan angle is a function of the refractive index of the glass and the roof angle.

- The steeper the roof and the higher the refractive index, the wider the fan angle and the longer the line for a given projection distance.

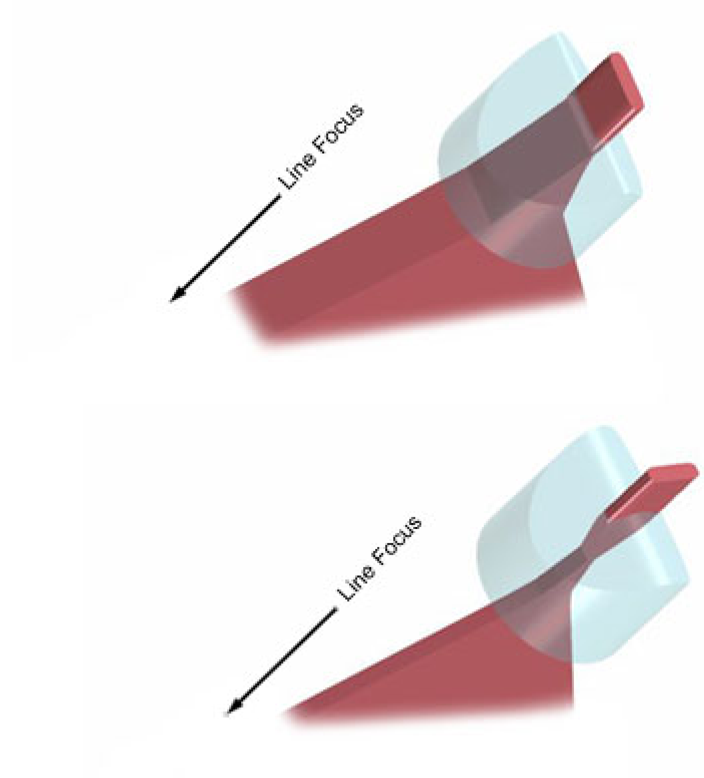




LASER BEAM SIZE

- The incident laser beams dimension determines the laser line thickness at a given projection distance.
- A collimated laser diode features an elliptical beam cross section allowing either a thin or thick line capability with a single diode module.
- With a narrow incident beam orientation, the beam's major axis is parallel to the Powell lens roof and a thin laser line with a small depth of focus is generated.
- With a wide incident beam orientation, the beam's major axis is perpendicular to the Powell lens roof and a thick laser line with a large depth of focus is generated.

- The images below clearly show the effect of beam shape/orientation on the line width.



LASER BEAM SIZE

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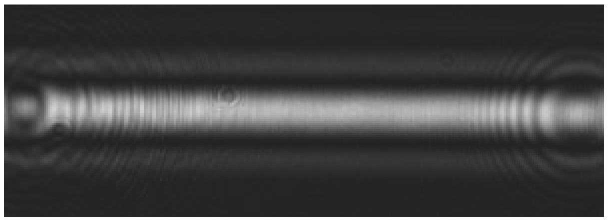
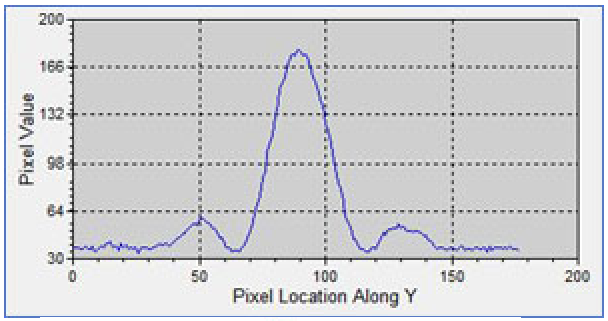
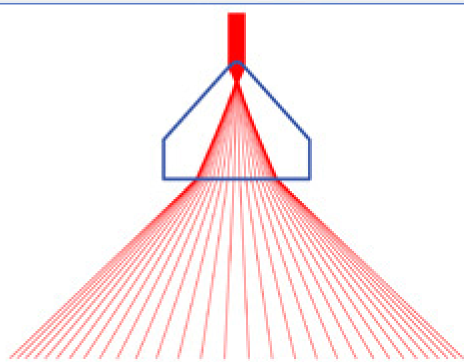
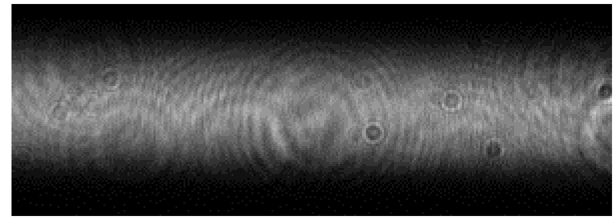
Narrow incident beam - thin line narrow depth of focus

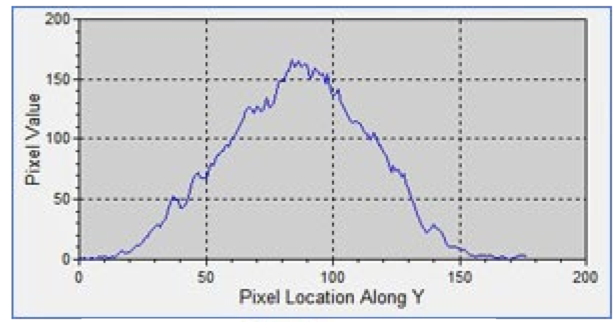


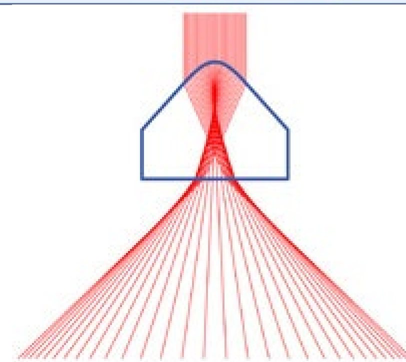




Wide incident beam - thick line wide depth of focus







LINE STRAIGHTNESS

A final laser line parameter worth mentioning is straightness.

- Real world projected laser lines are rarely perfectly straight.
- Most commonly, a bowed, or sometimes slightly "S" shape can occur.
- A bowed shape is most often caused when the incident laser beam enters the beam shaping optics at a non-normal angle of incidence.
- Because line straightness is dependent on optical alignment, it may therefore vary from unit-to-unit, as well as over time in a given system.
- Proper system calibration is therefore required to take line straightness into account and produce accurate measurement results.

LINE STRAIGHTNESS

FIG 1 - INTENSITY DISTRIBUTION ALONG THE LINE

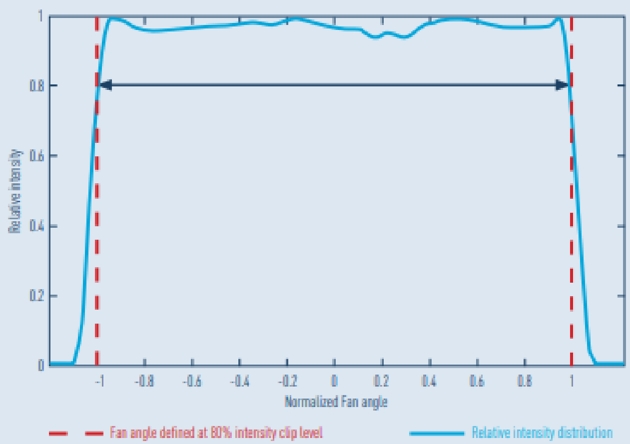
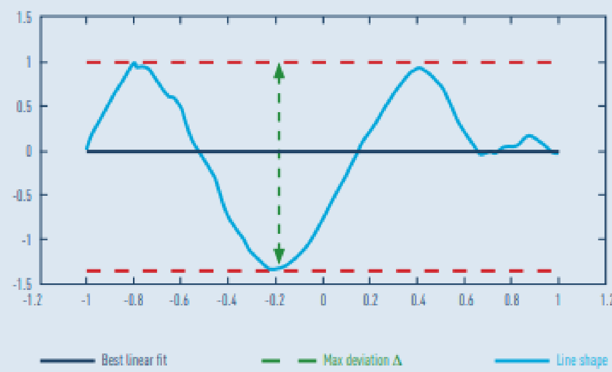


FIG 2 - LINE STRAIGHTNESS



SPECIFICATIONS

SPECIFICATIONS		VALUES
Uniformity (line intensity distribution along the line)[2]	$\frac{\text{Imax} - \text{Imin}}{\text{Imax} + \text{Imin}}$	20% (typical) ≤7.5%[1]
Relative intensity clip that define the fan angle		80%
Contained energy In the fan angle	$\frac{\text{Energy in fan angle}}{\text{total energy}}$	≥95%
Line Straightness (deviation from the best linear fit)[2]	$\frac{\Delta}{\text{L (line lenght)}}$	≤0.1% ≤0.05%[1]
Fan angle		1 to 90° [3]
Fan angle tolerance (line diverging angle from the tip of the laser)		+1.0/-0.5° (FA <30 °)
		+1.5/-0.5° (FA ≥30°)

LIGHT - SPECTRUM

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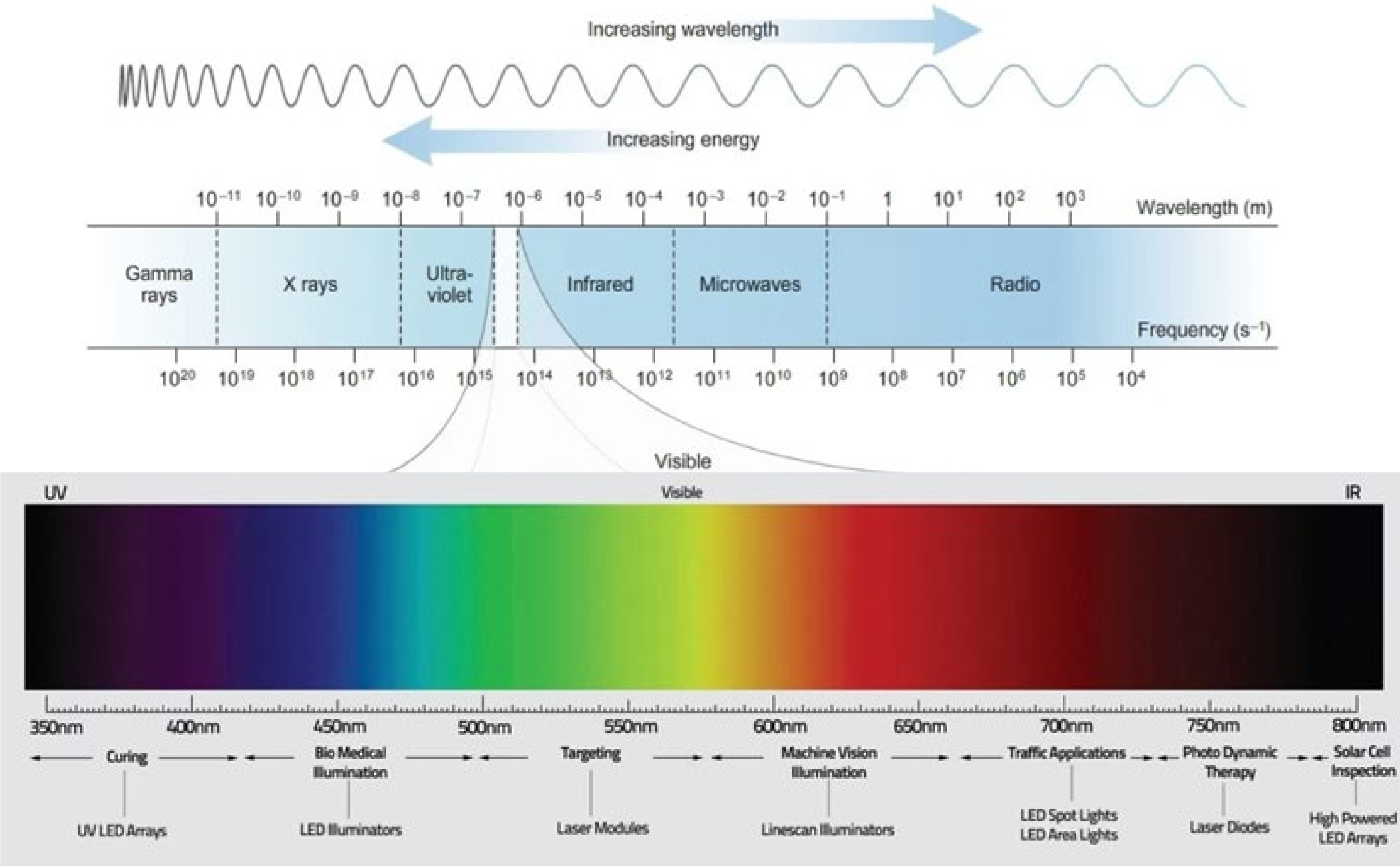
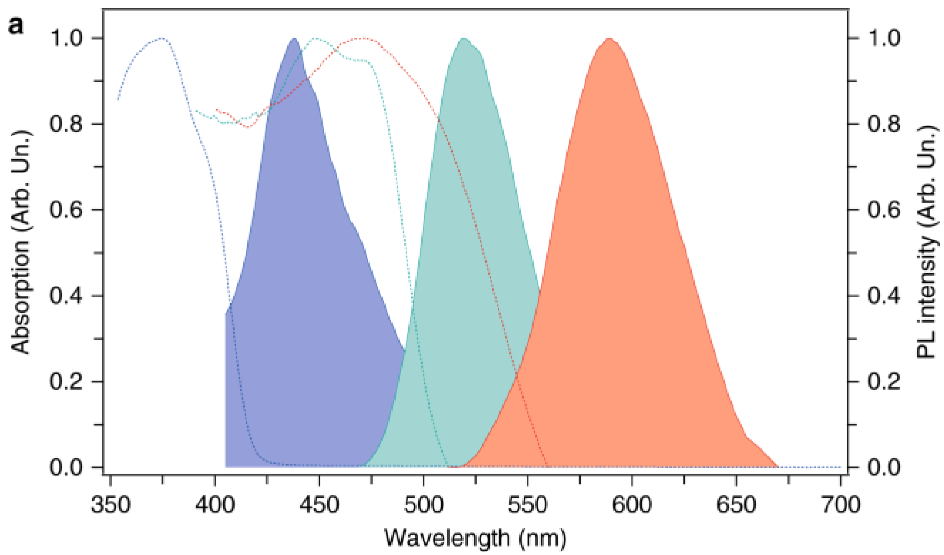
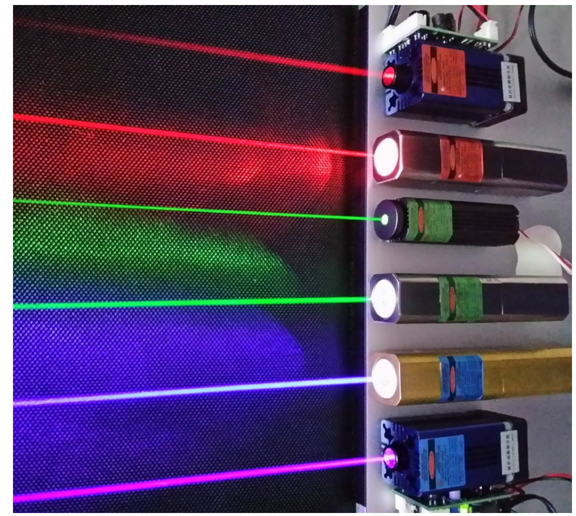
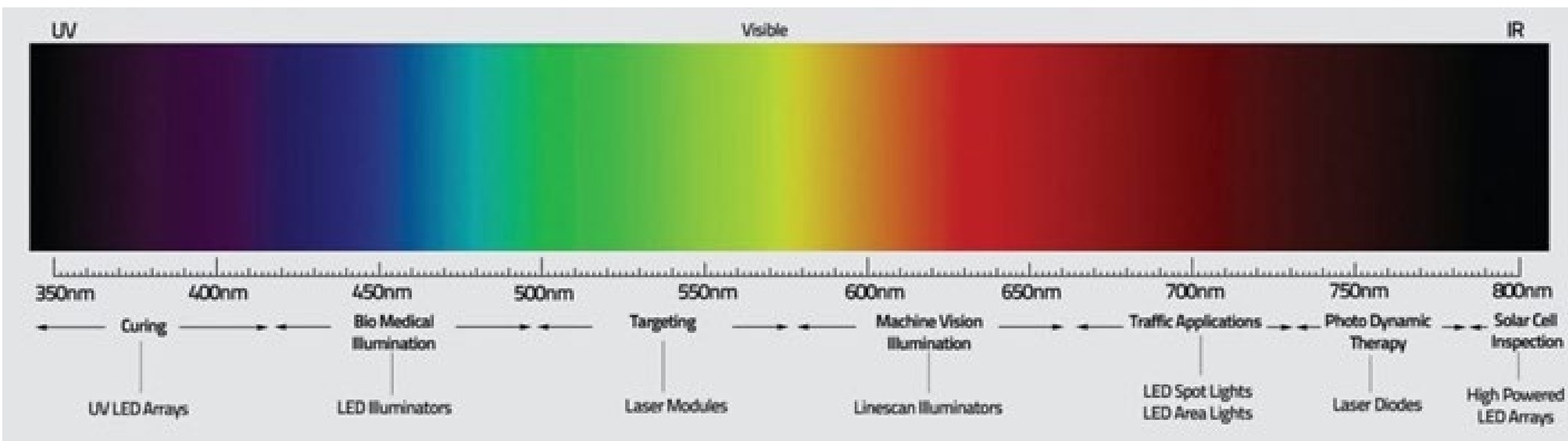


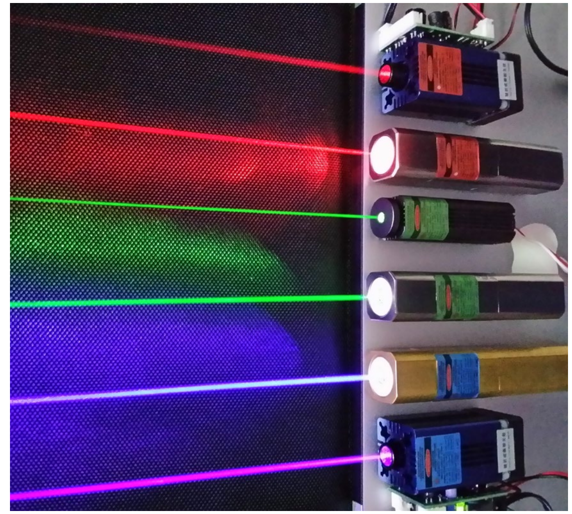
LIGHT - SPECTRUM

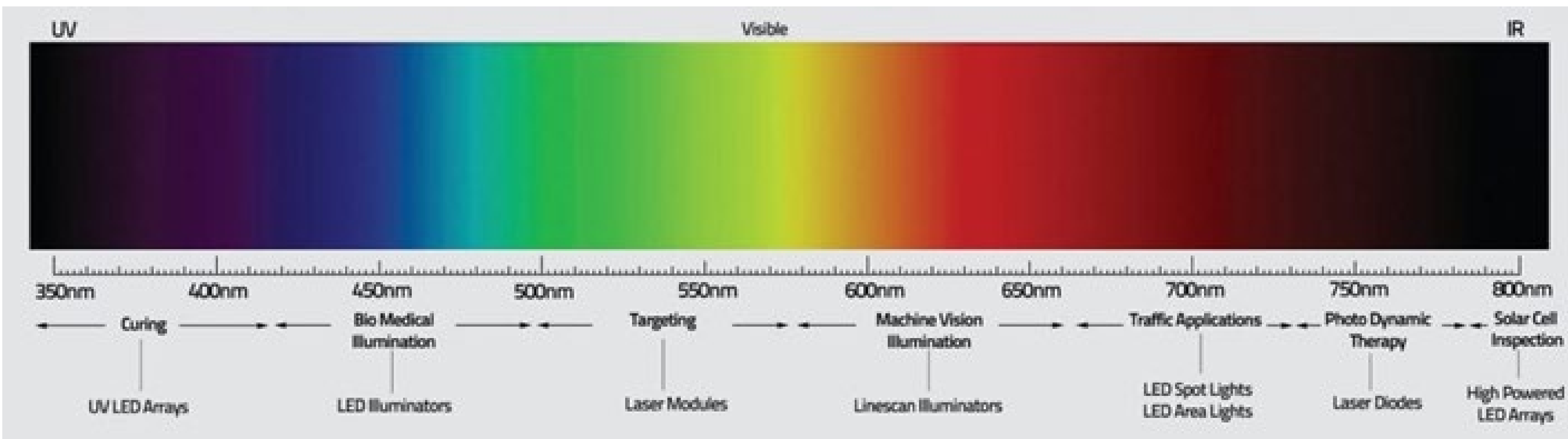






LIGHT - SPECTRUM



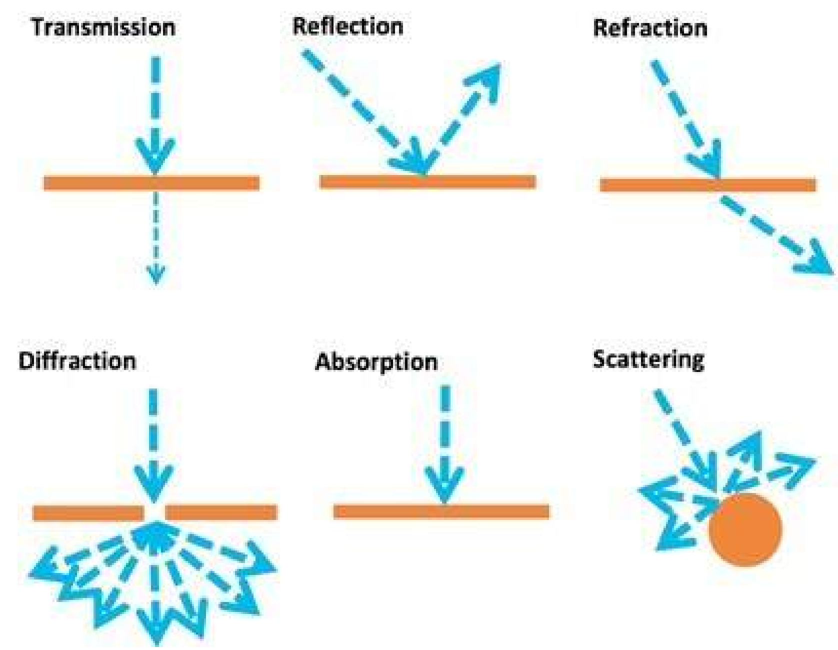


LIGHT REFLECTION / REFRACTION

Objects generally both reflect and refract light rays at the same time but in different proportions.

Opaque objects reflect most of the light rays, translucent objects refract most of the light rays.

How light is reflected and how light is refracted determines the translucency grade of the material.



LIGHT REFLECTION

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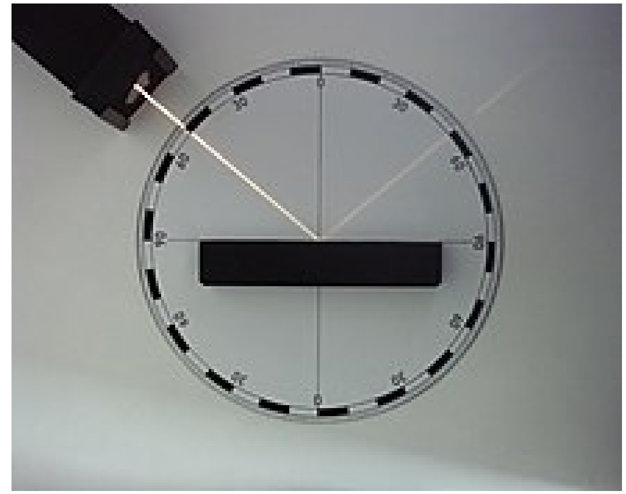
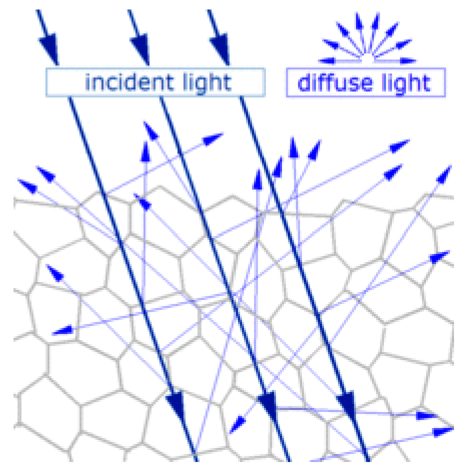
- Reflection is the change in direction of a wavefront at an interface between two different media so that the wavefront returns into the medium from which it originated.

- Common examples include the reflection of light, sound and water waves.

- The law of reflection says that for specular reflection the angle at which the wave is incident on the surface equals the angle at which it is reflected.

- Mirrors exhibit specular reflection.





LIGHT REFLECTION

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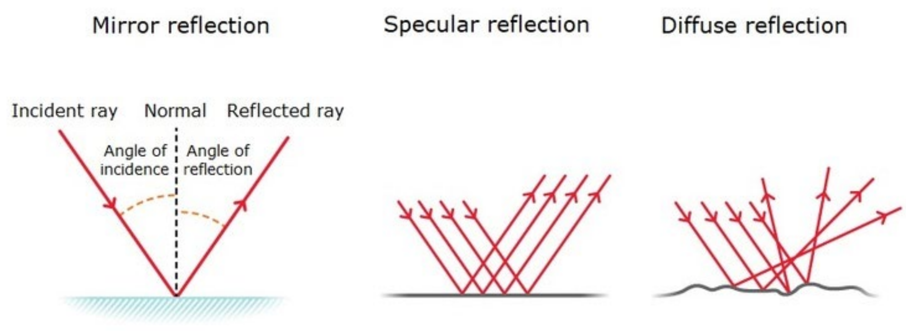
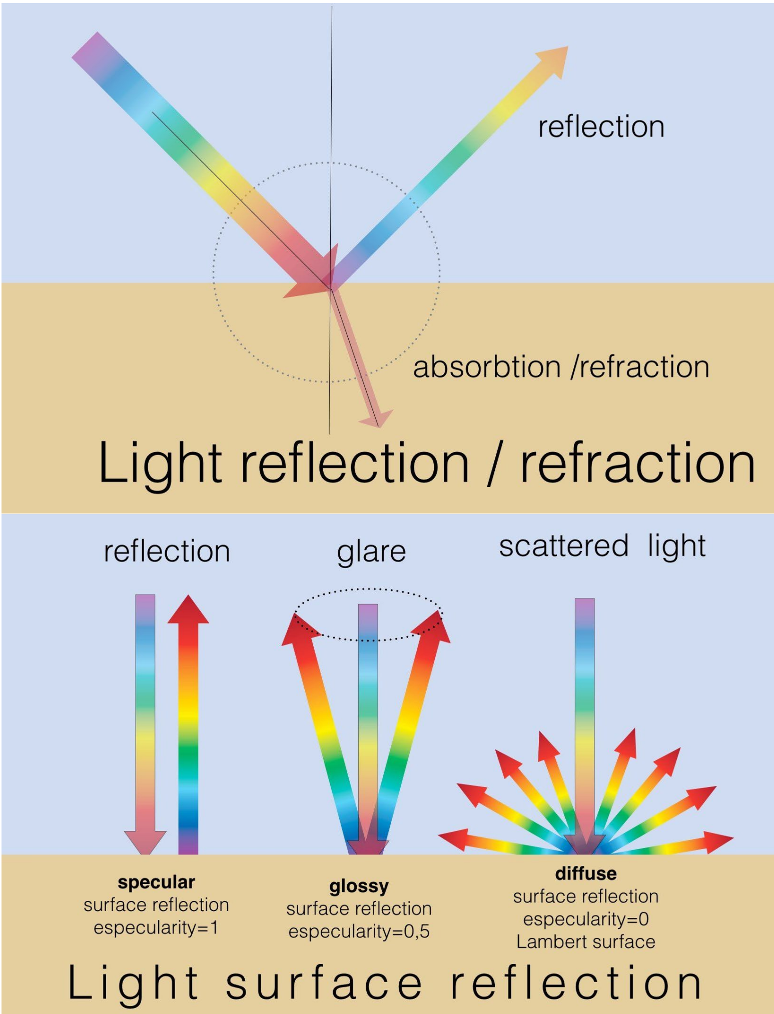
There are three laws which govern Reflection and Refraction. These can be very easily derived from geometry:

- Angle of Incident Ray with Normal (i) EQUALS Reflected Ray with Normal(r). $i = r$
- Popularly known as SNELL'S LAW: $n1 * \sin i = n2 * \sin e$ where i is same as above, e is angle of refracted beam with normal.
- The INCIDENT ray, REFLECTED ray, REFRACTED ray and the NORMAL at the point of incidence all lie in the same plane. The plane is referred as plane of incidence.



LIGHT REFLECTION



The way light is reflected depends very much on the surface of the object.

Depending on how light reflects you get different types of surfaces:

- Specular
- Glossy
- Diffuse

LIGHT REFRACTION

Light travels in a straight line, but when a light ray passes from one medium into a second medium the light direction bends at the boundary,

This bending effect is called **refraction** and is due to the different velocities at which light travels in each medium.

The relationship between the vacuum speed of light and the speed through a material can be expressed as a ratio called Refractive Index (RI).

Depending on this Refractive Index the angle of tis bend according to the snell's law.

$$RI_1 * \sin\alpha_1 = RI_2 * \sin\alpha_2$$
$$(The\ higher\ the\ RI > \ stronger\ the\ bending)$$

When light travels from a higher refractive index medium to a lower refractive medium, part of the light is trapped within the layer of higher RI, and the ray cannot scape keeping bounding internally

LIGHT REFRACTION

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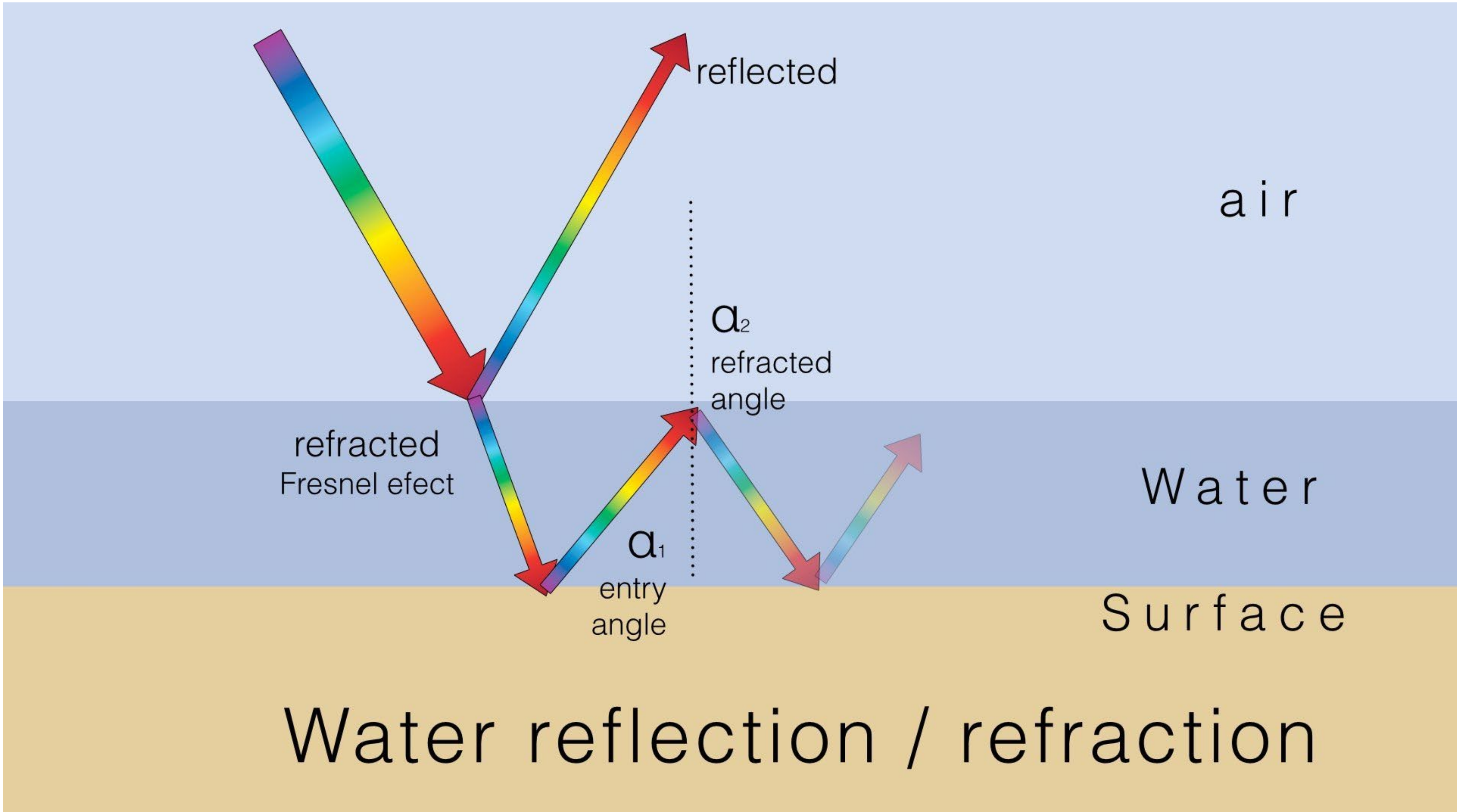
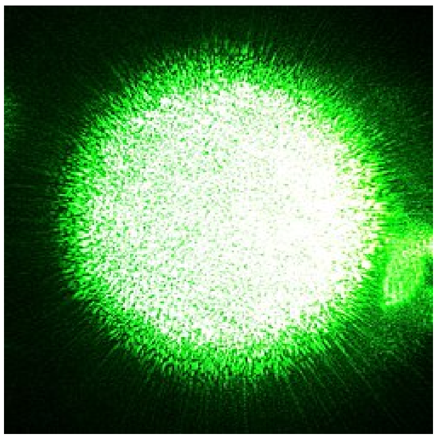
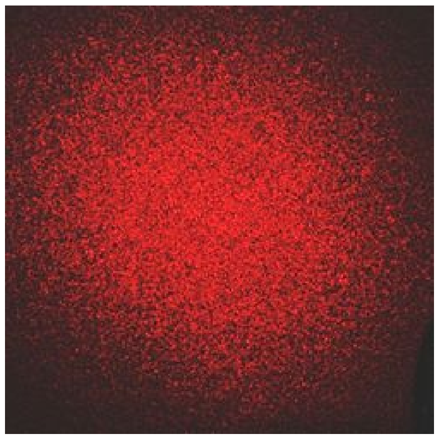


SPECKLE

- A speckle pattern is produced by the mutual interference of a set of coherent wavefronts. Speckles have come into prominence since the invention of the laser.





- Speckle patterns typically occur in diffuse reflections of monochromatic light such as laser light.

- Such reflections may occur on materials such as paper, white paint, rough surfaces, or in media with a large number of scattering particles in space, such as airborne dust or in cloudy liquids

SPECKLE

- The laser speckle pattern is produced by laser irradiation onto a rough surface, and the laser speckle particles are relative to the laser wavelength and the surface roughness of the sample and have more uniform distribution.

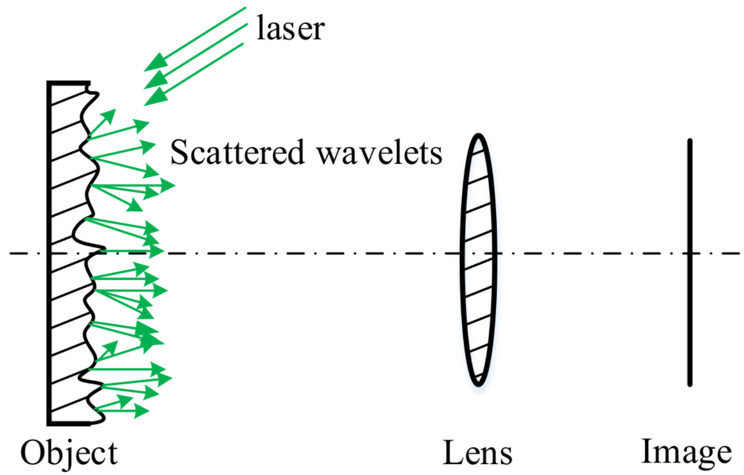


Fig. 1. The basic principle of laser speckle.

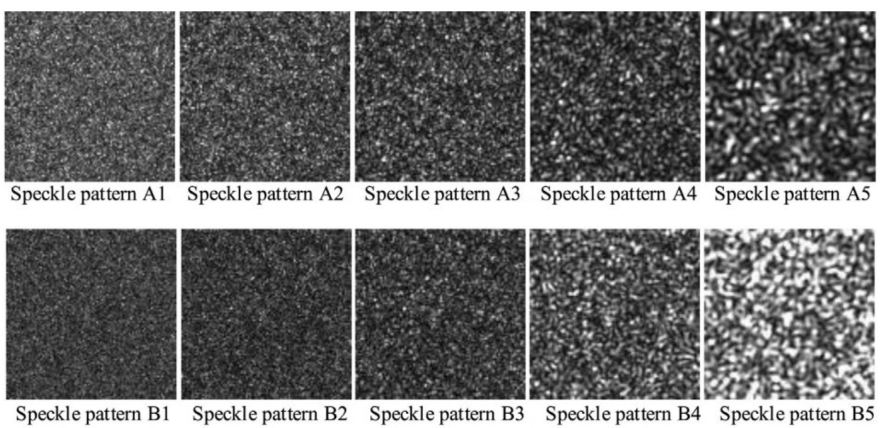
- The basic principle of laser speckle is shown in Fig. 1.

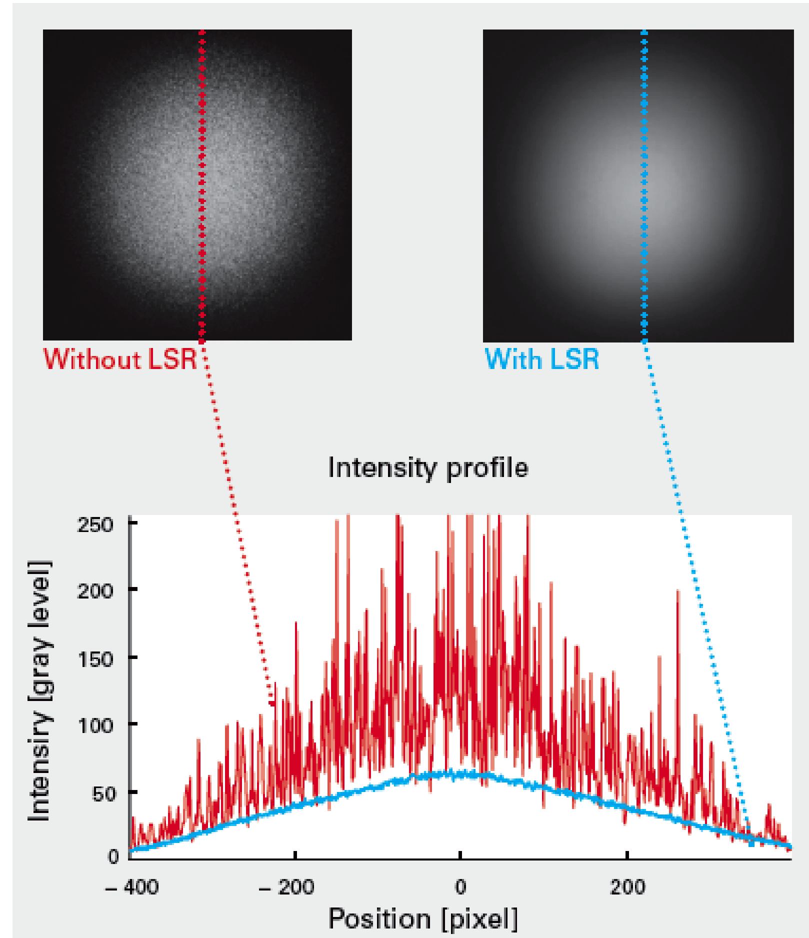
- When the laser irradiates the surface of an object with optical rough surface (compared with the laser wavelength), the surface of the object scatters numerous coherent wavelets, which interfere with each other in the space around the object

SPECKLE

- If the phase difference of the scattered wavelets satisfies the condition of constructive interference, the scattered wavelets will form a bright spot.

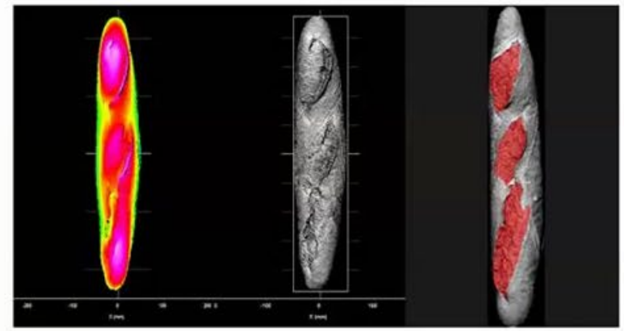
- On the contrary, if the phase difference satisfies the condition of cancellation interference, the dark spot will be formed.





CASE OF USE

INSPECCIÓN PRODUCTO Y DIMENSIONES



CASE OF USE

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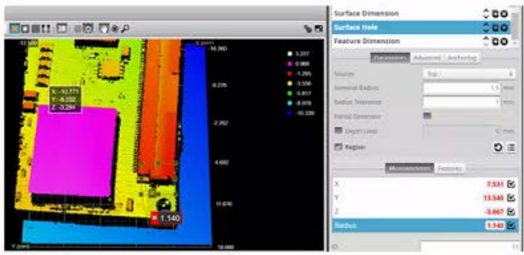
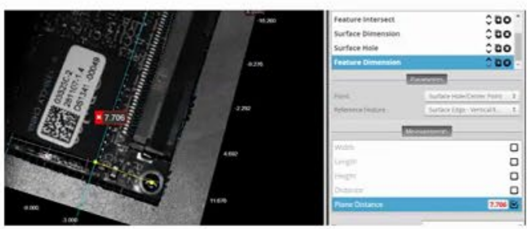
CONTROL EN PLACAS ELECTRÓNICAS



Posición y medida de orificios

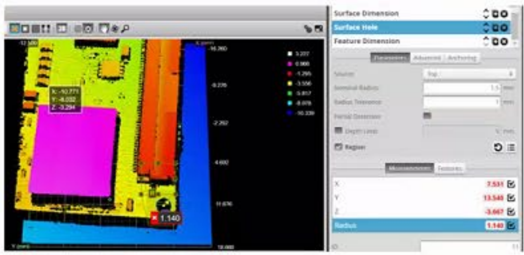
Altura SMD



Distancia entre diferentes puntos.

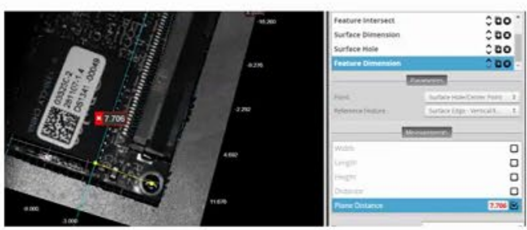
CASE OF USE

CONTROL EN PLACAS ELECTRÓNICAS



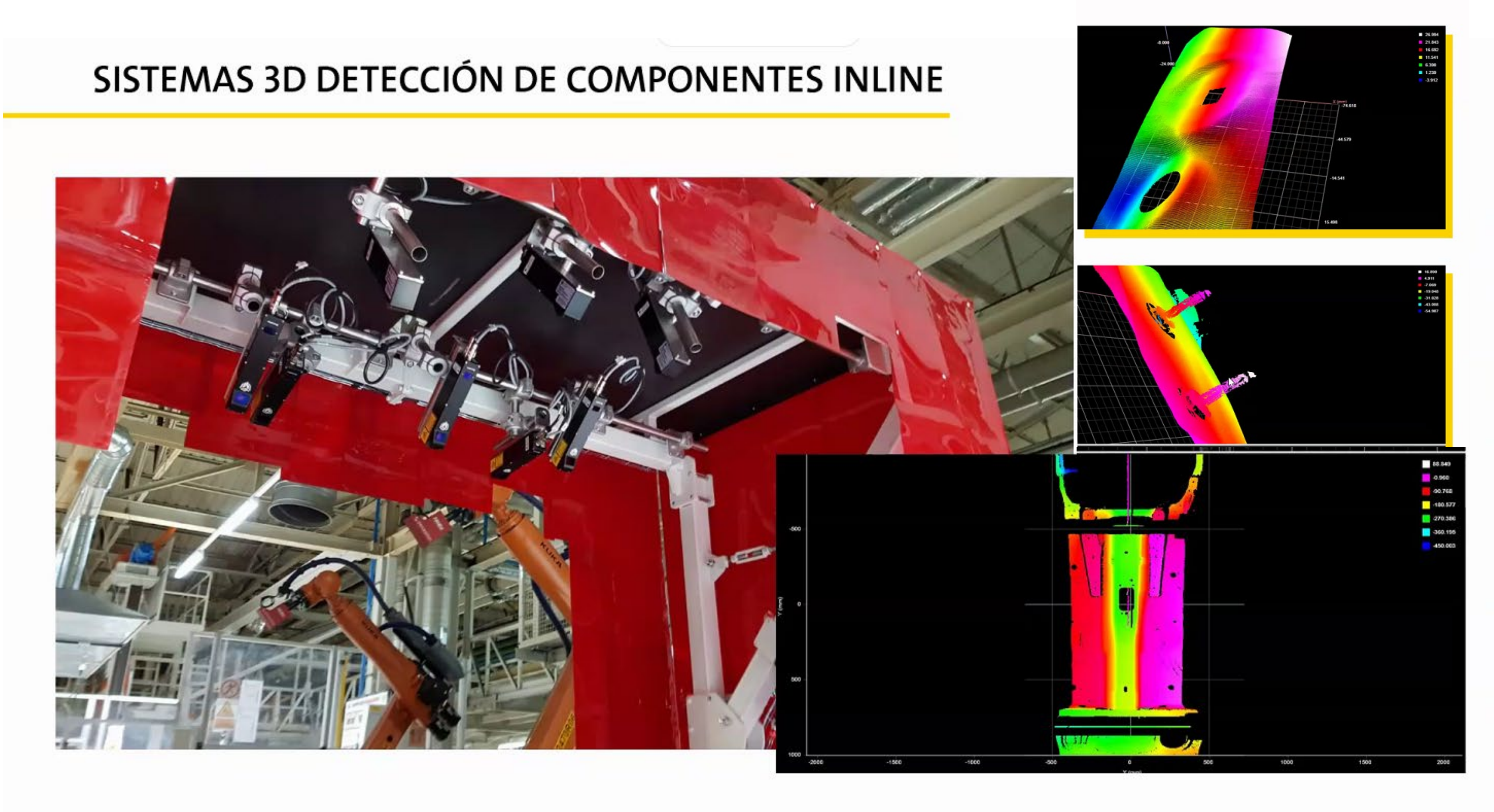
Posición y medida de orificios

Altura SMD



Distancia entre diferentes puntos.

CASE OF USE



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THANK YOU

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