3D Scanning

3D laser scanning is the technology to capture a physical object's exact size and shape using a laser beam to create a digital 3-dimensional representation of the same. 3D laser scanners produce "point clouds" of data from the surface of an object.

3D laser scanning is a way to capture a physical object's exact size and shape into the computer world as a digital 3-dimensional representation. This technique captures information like the complex geometry, intrigue shape, colorized texture, and other details of the 3D object that is scanned.

A 3D scanner collects information about the object being scanned as well as the environment (e.g. room) in which the object is present. If, a person is sitting beside the object that can also be 3D scanned.

3D scanners essentially create a digital copy of a real-world object. This digital copy or the 3D file can then be edited and 3D printed as per the user's requirements. Also, a 3D file can be used for further 3D modeling processes. Generally, in this 21st-century Engineers are using this technology for reverse engineering processes. 3D scanner files are generally compatible with CAD software and 3D printing slicer software.

A single scan is not enough to re-create a complete model of the object being scanned. Normally, hundreds of scans are necessary to capture all of the information from various sides and angles. All of these scans than have to be integrated through a common reference system known as ***alignment/registration***. Finally, the individual scans are merged to re-create the final model. This entire process of bringing together the individual scans and merging them is known as a ***3D scanning pipeline***.

3D Scanning Technology

3D laser scanning efficiently takes the measurements of contoured surfaces and complex geometries, requiring vast amounts of data for accurate description. Doing this using traditional measurement methods is impractical and time-consuming. Acquiring sizes and dimensions of free-form shapes creates precise point cloud data.

The basic working principle of a 3D scanner is to collect an entity's data. It can either be:

- an object
- an environment (such as a room)
- a person (3D body scanning)

In reverse engineering, a laser scanner's primary aim is to provide a lot of information about the design of an object which in the later stages gets converted to 3D CAD models, considering the compatibility of 3D scans and Computer Aided Design (CAD) software. 3D scans are even compatible with 3D printing, requiring specific computer software.

Types of 3D Scanning Technologies

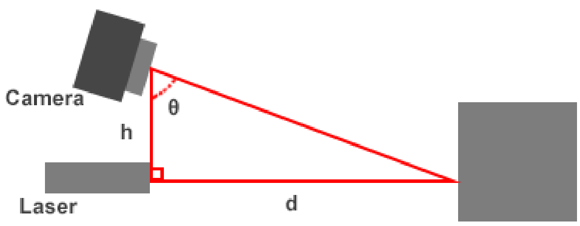
1. **LASER triangulation 3D scanning technology.**
2. **Structured light 3D scanning technology.**
3. **Photogrammetry.**
4. **Contact-based 3D scanning technology.**
5. **LASER pulse-based 3D scanning technology.**

1. Laser triangulation 3D scanning technology:

In this category, the laser scanner projects a laser beam on a surface and measures the deformation of the laser ray.

Laser scanning is often considered to be more versatile than other 3D scanning technologies. As the name indicates, this category of 3D printers projects or delivers laser beams onto the surface of the real-world object. The laser beam returns back to the sensor after being reflected. The 3D scanner gathers and interprets the geometric information based on the time gap between projection and reflection. The scanner uses a camera to record where the laser beam intersects with the object.

The angles of the camera and the laser beam make the scanner identify the exact location where the laser dot hits the object. In addition to scanning objects, laser scanning technology measures distances accurately and precisely. But the 3D scanning technology is considered to be less precise than structured light scanning. Also, it is used primarily by larger 3D scanners to scan large objects like buildings and cars.



h = distance between camera and laser (known)
θ = angle betwen laser and scanner (known)
d = distance between scanner and object (unknown)

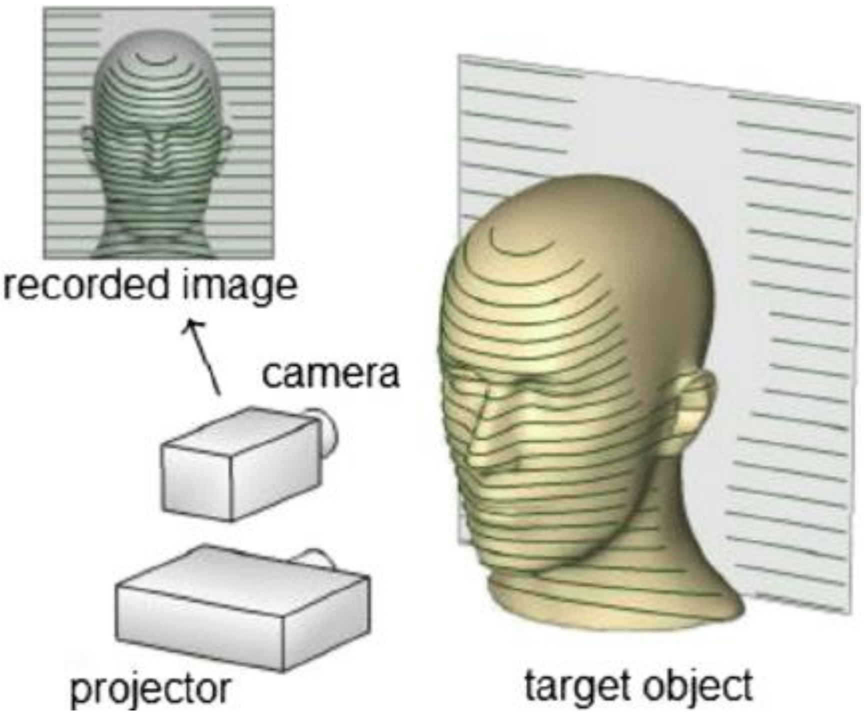
$$d = h * \tan(\theta)$$

2. Structured light 3D scanning technology:

This technology involves projecting structured patterns of light on an object and acquiring a surface's shape by measuring the light pattern's deformation.

This category of scanners produces 3D models by performing two important tasks simultaneously – casting geometric patterns onto the real-world object and taking photographs using a camera. While taking photographs, the camera captures or logs in deviations of every image. While producing 3D models, the 3D scanner determines the location of all existing points based on the displacement of patterns.

These 3D scanners replicate a real-world model digitally and accurately by scanning it continuously from various angles. Also, they use specialized software to create the 3D model accurately by stitching these scanned images. The use of structured light makes this 3D scanning technology deliver extremely precise measurements. Also, structured light 3D printing technology is used widely by stationary and portable 3D scanners.



3. Photogrammetric technology:

It is also known as a 3D scan from photography. It reconstructs an object from 2D to 3D and has specific computational geometrical algorithms for the task. Photogrammetry is cheap, precise, and used to scan large objects such as buildings and stadiums.

This 3D scanning technology produces digital models by stitching multiple images of the same real-world object taken from various angles. The photogrammetric scanners use specialized software to stitch images taken using digital cameras, mobile devices, and camera drones. The software integrated images seamlessly and accurately by identifying pixels corresponding to the exact physical point.

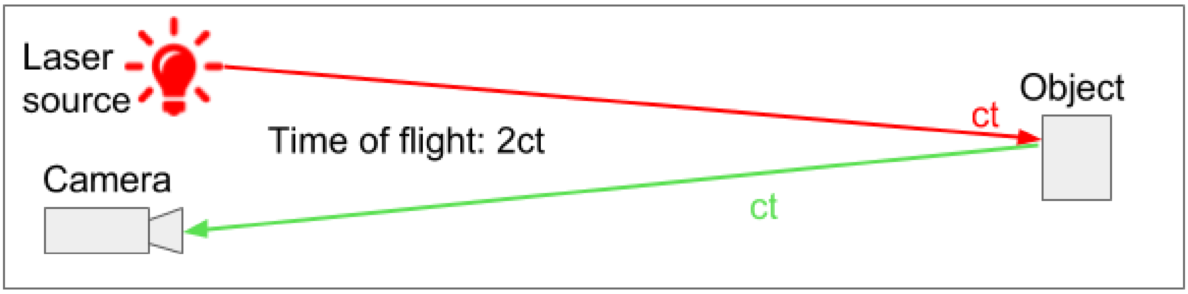
Engineers these days use drone cameras to capture images of mountains, statues, buildings, and large structures. The photogrammetry scanning technology makes it easier for them to create digital models of these large structures by stitching the aerial photographs. Also, this category of 3D scanners helps 3D artists to scan animals and human beings without putting in extra time and effort.

4. Contact-based 3D scanning technology: This process requires contact between the probe and the object, where the probe is moved firmly over the surface to acquire data.

As the name suggests, this type of 3D scanner produces 3D models digitally by contacting or touching the real-world object physically. The 3D engineers need to ensure that the object to be scanned is held in place firmly before starting the scanning process. The accuracy of the contact-based 3D scanning process depends on a slew of factors – timing, movement, and vibration.

Also, contact 3D scanners often alter or deform the object while creating 3D models. Engineers have to make alterations to ensure accuracy and precision. That is why; contact scanners are used primarily for quality control purposes. The engineers do not use this type of 3D scanner for the conservation of objects.

5. Laser pulse 3D scanning technology: This unique process collects geometrical information by evaluating the time a laser beam takes to travel between its emission and reception. It is also known as time of flight technology.



The 3D scanners developed using time-of-flight (TOF) technology captures detailed information about a three-dimensional object using a range imaging camera system. The range imaging camera system resolves the distance between the camera and the real-world object using TOF technology. TOF technology makes the scanner measure the amount of time the infrared light or laser beam takes to reflect back.

This type of 3D scanners is developed with highly accurate sensors. But they still fail to deliver precise measurements as the speed of light is impacted directly by a slew of factors, including temperature and humidity. That is why; engineers often opt for TOF 3D scanning technology while creating 3D models of large structures and objects. However, the 3D scanning technology is effective in capturing images of an object in real-time by tracking movements seamlessly.

Advantages and disadvantages of each type of 3d scanning technology

Photogrammetry 3D Scanning

Pros

✅It's cheap because it doesn't require specialized equipment

✅Allows you to scan very large objects such as buildings

✅It captures the texture of the object pretty accurately

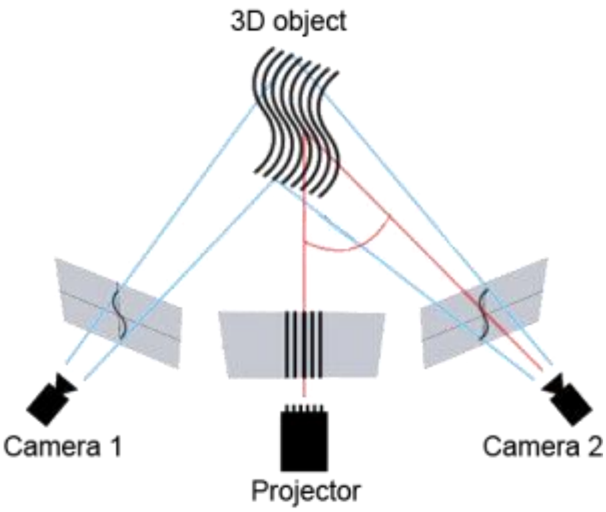
✅Allows to make ground analysis using drones

✅It can be very precise

Cons
❌It's not very easy: Since we don't use specialized scanners we don't have the convenience of these, which are often plug-and-play

❌Requires specialized software and computers with good processing power

Structured Light Scanning



Pros
✅It is usually very easy to get good results using commercial scanners

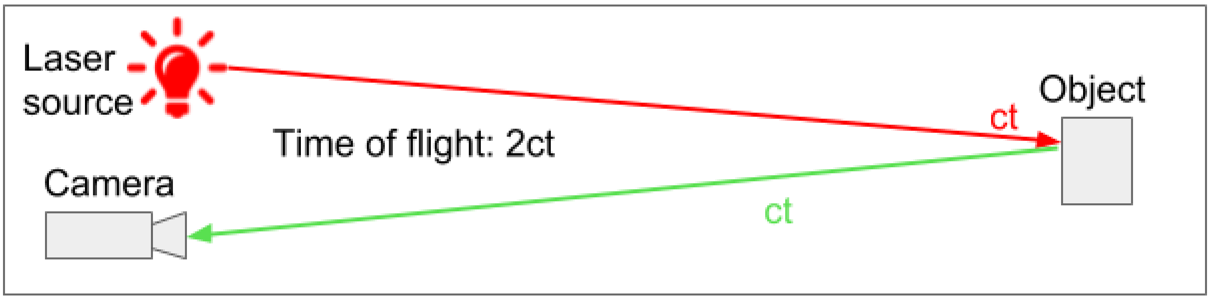
✅High-precision models

Cons
❌Cannot be used outdoors or in brightly lit environments

❌You can't scan very large objects

❌Scanners can be expensive

Laser Scanning



Pros

✅It's a highly versatile technology

✅Allows not only to scan objects but also to measure distances, so it has many uses in robots and vehicles to scan the environment

✅Allows you to make very low resolution scans at high speed, measuring only a few points on the object

Cons

❌Does not work well in brightly lit environments

❌In general, it is less accurate than scanning with structured light and also more error-prone

❌Expensive equipment

Types of 3D Scanners

1. Short range 3D scanners

2. Medium and long range 3D scanners

3. Coordinate Measuring machine

4. Arm based 3D Scanners and Probe systems

5. Optically tracked 3D Scanners and Probe Systems

1. Short Range 3D Scanners

Short Range 3D scanners typically utilize a Laser triangulation or Structured Light technology.

- **Laser based 3D Scanners**

Laser based 3D scanners use a process called trigonometric triangulation to accurately capture a 3D shape as millions of points. Laser scanners work by projecting a laser line or multiple lines onto an object and then capturing its reflection with a single sensor or multiple sensors. The sensors are located at a known distance from the laser's source. Accurate point measurements can then be made by calculating the reflection angle of the laser light.

Laser scanners are very popular and come in many designs. They include handheld portable units, arm based, CMM based, long range, and single point long range trackers.

Benefits of 3D Laser Scanners

- Able to scan tough surfaces, such as shiny or dark finishes
- Less sensitive to changing light conditions and ambient light
- Often more portable
- Simpler design – easier to use and lower cost

- **Projected or Structured Light 3D Scanners**

Historically known as "white light" 3D scanners, most structured light 3D scanners today use a blue or white LED projected light. These 3D scanners project a light pattern consisting of bars, blocks or other shapes onto an object. The 3D scanner has one or more sensors that look at the edge of those patterns or structure shapes to determine the objects 3D shape. Using the same trigonometric triangulation method as laser scanners the distance from the sensors to the light source is known. Structured light scanners can be tripod mounted or hand held.

Benefits of Structured light 3D Scanners

- Very fast scan times – as fast as 2 seconds per scan
- Large scanning area – as large as 48 inches in a single scan
- High resolution – as high as 16 million points per scan and 16 micron (.00062") point spacing
- Very high accuracy – as high as 10 microns (.00039")
- Versatile – multiple lenses to scan small to large parts in a single system

- Portable – hand held systems are very portable
- Eye safe for 3D scanning of humans and animals
- Various price points from low cost to expensive depending on resolution and accuracy

2. Medium and Long Range 3D Scanners

Long range 3D scanners come in two major formats - Pulse based and phase shift – both of which are well suited for large objects such as buildings, structures, aircraft, and military vehicles. Phase shift 3D scanners also work well for medium range scan needs such as automobiles, large pumps and industrial equipment. These scanners capture millions of points by rotating 360 degrees while spinning a mirror the redirects the laser outward towards the object or areas to be 3D scanned.

Laser pulse-based 3D scanners

Laser pulse-based scanners, also known as time-of-flight scanners, are based on a very simple concept: the speed of light is known very precisely. Thus, if the length of time a laser takes to reach an object and reflect back to a sensor is known, the distance from sensor to object is known. These systems use circuitry that is accurate to picoseconds to measure the time it takes for millions of pulses of the laser to return to the sensor, and calculates a distance. By rotating the laser and sensor (usually via a mirror), the scanner can scan up to a full 360 degrees around itself.

Laser Phase-shift 3D Scanners

Laser phase-shift systems are another type of time-of-flight 3D scanner technology, and conceptually work similarly to pulse-based systems. In addition to pulsing the laser, these systems also modulate the power of the laser beam, and the scanner compares the phase of the laser sent out and returned to the sensor. Phase shift measurement are typically more accurate and quieter but are not as flexible for long range scanning as pulse-based 3D scanners. Laser pulse based 3D scanners can scan objects up to 1000m away while phase shift scanners are better suited for scanning objects up to 300m or less.

Benefits Long Range 3D Scanners

- 3D Scan millions of points in a single scan – up to 1 million points per second
- Large scanning area up to 1000 meters
- Good accuracy and resolution based on object size
- Non-contact to safely scan all types of objects
- Portable

3. Coordinate Measuring Machine (CMM)

A coordinate measuring machine (CMM) is used primarily to inspect parts. The machine can be controlled manually or through controlled offline through software and computers. Measurements are defined by attaching a probe to the machine. The probe typically has a small ball at the end of a shaft of a known diameter. The CMM is then programed to contact the part. When the machine senses contact of the probe tip a measurement value in taken in XYZ space. The most common type of CMM is a bridge type which has 3 axis X, Y & Z. The probing system that is attached many times can rotate providing an additional 3 axis for a total of 6 degrees of freedom (DOF). To very accurately measure parts to a few microns, CMM's are typically deployed in a very controlled inspection room that includes a reinforced floor, controlled humidity and temperature, and isolation from vibration and other forces that could affect the accuracy. In addition, most CMM's have a large granite table surface that is perfectly level. Parts are fixtured onto the granite table so that there is no movement during the measuring process.

Benefits of CMM's

- One of the most accurate ways of measuring an object
- Small to large parts can be measured with the proper machine
- Industry standards and certifications for measurements and software exist
- Many styles and sizes of machines exist from many manufactures

4. Arm based 3D Scanners and Probe systems

An armed based 3D scanning or probing system is similar to a coordinate measuring machine (CMM) in the fact it can use a touch probe to measure a part. In addition to the probe, many arm based systems also have an attachable 3D laser scanner for collecting large amount of points. Software keeps track of the joint movements of the arm to know where it is in 3D space at all time. Arm based systems work by attaching the articulated arm to either a table or sturdy base. Then the arm is held by a hand grip at the end and moved around to probe or scan. The main advantage of these systems is they are much more portable then a CMM and can be used in a shop floor environment.

Benefits of Arm based 3D Scanners and Probe systems

- Portable system

- Good accuracy on small to medium size parts
- Ability to probe and scan a single part

5. Optically tracked 3D Scanners and Probe Systems

Optically tracked 3D scanning and probing systems use a set of cameras to track the location of the 3D scan head or probe in 3D space. These systems offer advantages over arm based systems including freedom of movement, better accuracy over distance, and the ability to include “dynamic referencing”. Dynamic referencing systems work by attaching targets or led lights to the object you are scanning or probing. This allows the camera system to track the part and scan or probe head separately from each other. The net result is the part can be moving even while scanning and no loss of accuracy or data quality occurs. In addition, the camera system can also be moved around allowing you to scan large parts in one setup.

Benefits of optically tracked 3D scanning and probing systems

- 3D scanning and probing in the same system
- Freedom of movement
- Large 3D scanning volume
- Ability to probe and scan even while the part is moving with no loss of accuracy
- Very portable

Microsoft Kinect Sensor

Recent advances in 3D depth cameras such as Microsoft Kinect sensors (www.xbox.com/en-US/kinect) have created many opportunities for multimedia computing. Kinect was built to revolutionize the way people play games and how they experience entertainment. With Kinect, people are able to interact with the games with their body in a natural way. The key enabling technology is human body-language understanding; the computer must first understand what a user is doing before it can respond. This has always been an active research field in computer vision, but it has proven formidably difficult with video cameras. The Kinect sensor lets the computer directly sense the third dimension (depth) of the players and the environment, making the task much easier. It also understands when users talk, knows who they are when they walk up to it, and can interpret their movements and translate them into a format that developers can use to build new experiences.

Kinect's impact has extended far beyond the gaming industry. With its wide availability and low cost, many researchers and practitioners in computer science, electronic engineering, and robotics are leveraging the sensing technology to develop creative new ways to interact with machines and to perform other tasks, from helping children with autism to assisting doctors in operating rooms. Microsoft calls this the Kinect Effect. On 1 February 2012, Microsoft released the Kinect Software Development Kit (SDK) for Windows (www.microsoft.com/en-us/kinectforwindows), which will undoubtedly amplify the Kinect Effect. The SDK will potentially transform human-computer interaction in multiple industries—education, healthcare, retail, transportation, and beyond.