

3D Scanning Options

How to choose digitizing technologies.

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The 3D Imaging and Modeling Metrology Group of the National Research Council of Canada and InnovMetric Software, Inc., maker of PolyWorks software, studied 3D measurement hardware technologies and external frame of reference (EFR) monitoring techniques as a basis for research into developing 3D measurement standards. DE looks at some of their findings.

With multiple digitizing technologies available, it is often not obvious which might best serve your needs. This study looked at principles, characteristics and key advantages and disadvantages of both low- and high-density scanning techniques.

Low-density, Single-point Techniques

Single-point measurement tools target and measure one or more specific points at a time by mechanical contact or optical non-contact methods. There are five key reasons that both mechanical contact and optical non-contact, low-density methods are still relevant and important (see Table 1):

1. When combined with mechanical EFR tracking and controlling software, they can produce automated, rapid, repeated 3D surface measurements.
2. They are suitable for measuring parts with highly reflective or transparent surfaces.
3. Difficult-to-reach areas such as deep holes or underbodies may be easier to measure.
4. They can rapidly measure small objects or those with a small number of features.
5. In general, they provide very accurate measurements.

Mechanical measuring methods involve moving a spherical stylus or probe tip to contact an object's surface and measuring the (x,y,z) position of the tip's center.

Optical measuring methods project light generated from a lamp, bulb or laser, onto a surface, a reflective marker affixed to a surface, or other reflectors such as spherically mounted retro-reflectors (SMRs). The absolute or relative distance between the scanner and the object is calculated based on

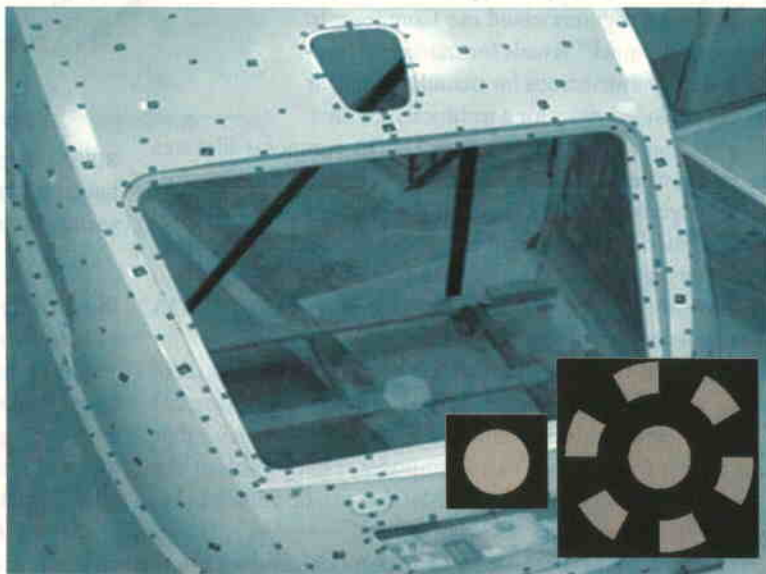


FIGURE 1: This physical object is covered with targets, ready for photographing. Photogrammetry software extracts geometric information of the reflective targets' centers.

FIGURE 2 (INSET): Simple and coded reflective targets.

the speed of light and the travel time to and from the object (see Figures 1 and 2).

Mechanical tracking for single point measuring techniques retains the same coordinate system as the scanned object. Fixed or portable CMMs' base or zero does not change as measurements are made.

Optical tracking for single-point measuring techniques involves either a laser tracker following the center of a reflective probe, or light-emitting or passive targets affixed to a touch probe mount. Again, these tracking technologies remain in the same coordinate system as the object.

Conceptually, this is similar to a camera pivoting on a tripod mount to take multiple photos of an object, but the tripod is not moved to a different vantage point.

External Frame of Reference

EFR hardware or software monitors the digitizer's position in real time as it moves around an object, and aligns its many

images into a common coordinate system to fully capture and assemble the object's 3D geometry. EFR is used for precise measurements of large (>1 meter) or complex objects, and can be combined with either low- or high-density digitizing technologies. EFR is required whenever digitizing hardware is moved out of the coordinate system of the object—conceptually equivalent to moving a tripod-mounted camera to another vantage point.

High-density, Non-contact Digitizing

High density, non-contact digitizing methods provide a much faster option for measuring large numbers of points without requiring targets. Since the 1980s, non-contact methods have been preferred for large or free-form surfaces, objects with many features, flexible objects, or fragile objects, because surfaces are not touched by a probe.

Active High-density Scanning

High-density digitizing can be active or passive, but active scanning is the more commonly used method. Conceptually, energy is projected onto a physical part, reflected, and viewed or sensed by an electronic detection device (typically a camera or sensor). Analyzing the position of the reflected energy's image determines (x,y,z) coordinates of the object (see Figure 3).

Surface 3D digitizers capture an object's external visible surfaces. Volumetric 3D digitizers capture both exterior visible surfaces and hidden interior geometries.

Identify Your Needs

To help you evaluate 3D scanning technologies appropriate for your needs, visit deskeng.com/articles/aaazje.htm for graphics that present performance ranges and technology definitions.

External frame of reference (EFR) techniques have their own performance specifications that are indicated separately. According to Marc Soucy, president of InnovMetric, EFR techniques can influence overall measurement results, and their performances should be taken into consideration.

Other important factors to consider include:

- number of operators required
- fixture requirements, system footprint and power
- setup, data collection and data processing time
- calibration procedures
- formats of output files and results
- availability of options such as continuous or energy-saving modes, wireless data transfer, remote controls and the dynamic compensation for thermal expansion, temperature, vibration or other environmental conditions.

Destructive Volumetric 3D techniques slowly grind away a small layer of material, digitize what is seen, and repeat until the entire part has been fully digitized and destroyed.

Table 1: Low-density/Single-point Measurement Technologies

Name of Method	Contact/ Non-contact Method	Incremental or Absolute Distance Measurement (ADM)	Detection Method	What is Measured or Algorithmically Extracted	Type of Tracking Along Surface	Portability
Traditional Fixed CMM	Contact	Absolute	Center of Spherical Tip Contacts Surface	Probe tip's center (x,y,z) position is recorded, true surface calculated based on a compensation vector, displacement in time	Fixed multi-axis coordinate measurement machine (CMM)	Immobile technique requiring part be brought to the measurement tool
Portable CMM: Articulated Arm	Contact	Absolute	Center of Spherical Tip Contacts Surface	Probe tip's center position is recorded, true surface calculated based on a compensation vector, displacement in time	Six-axis or a seven-axis articulated (jointed) arm	Arm with many flexible joints, brought near the part to be measured
Portable CMM: Laser Tracker	Contact	Either or both, interferometer based or ADM	Center of a spherically mounted retro reflector (SMR) contacts surface	Laser beam is locked on center of SMR; azimuth and elevation angles of laser beam are measured, distance between laser tracker origin and SMR is measured	Laser beam tracks the 3D coordinates of SMR's center	Portable; tracker is brought near the part to measure
Portable CMM: Optical Tracker	Contact	Absolute	Center of a spherical tip mounted with light-emitting or passive targets contacts surface	Center of all visible light-emitting or passive targets affixed on contact probe	Tracks reflective or emitting targets	Portable; tracker is brought near the part to measure
Photogrammetry	Non-contact (but targets do contact object)	Absolute	Optical: Digital camera photographs targets on a surface	Center of light-emitting or passive targets affixed or mounted on object's surface	Tracks targets whose position are determined by photogrammetry	Portable; cameras are brought to the part to be photographed

Destructive methods are typically used for smaller, low cost, mass-produced parts for which internal structure is crucial.

Most digitizers used in industrial applications use non-destructive techniques. About 90% of close-range, high-density digitizers belong in the triangulation category enclosed in red.

Table 2 summarizes principles and characteristics of high-density measuring technologies and associated EFR methods.

Triangulation-based Laser Techniques

Laser triangulation digitizers project a line or a single spot (projected as a line using mirrors) onto an object, which reflects and is imaged by a camera. Knowing projection and collection angles relative to a baseline determines a triangle's dimensions and the coordinates of a point on the surface.

These close-range laser techniques offer excellent depth resolution on large parts, and can measure small detail such as bor-

Table 2: High-density Non-contact Measurement Technologies

Technology Name(s)	Category	Active or Passive	Surface or Volumetric	Type of Radiant Energy	Detection Method	Principle	Typical Beneficial EFR Technologies
Laser Flying Spot Triangulation	Triangulation	Active	Surface	Laser	Optical detection of a single laser spot by camera sensors or CCDs	Reflected light is focused onto a camera. Known projection and collection angles relative to a baseline determines the dimensions of a triangle and coordinates of surface point.	Custom encoder-based translation or rotation systems, laser trackers, optical trackers, photogrammetry, articulated arm portable CMM, robots
Laser Line Scanning	Triangulation	Active	Surface	Laser	Optical detection of projected laser line by camera sensors or CCDs	Reflected light is focused onto a camera. Known projection and collection angles relative to a baseline determine the dimensions of a triangle and coordinates of surface point.	Custom encoder-based translation or rotation systems, laser trackers, optical trackers, photogrammetry, articulated arm portable CMM, robots
Fringe-based Projection Digitizing	Triangulation	Active	Surface	White light from halogen or other lamp source	Optical detection of projected light fringe patterns on camera sensors or CCDs	Fringe patterns of light of various resolutions are used to uniquely determine projection directions over object's surface. Reflections are collected in one or more cameras and analyzed.	For areas <1m x 1m: photogrammetry, turntable and gantry, or best-fit alignment using overlapping areas. For large areas >1m x 1m: photogrammetry, optical tracker, mechanical tracker or robot
Conoscopic Holography	Triangulation	Active	Surface	Laser	Optical detection of polarized light interference patterns on CCDs	Reflected light is diffused through a crystal and projected onto a CCD. Frequency analyses of the resulting diffraction patterns determines distance to the object, producing 3D holograms.	Fixed CMM or 3-axis mechanical tracking system
Industrial Computer Tomography (CT)	Computer Tomography	Active	Volumetric	X-ray	X-ray detection	Attenuated x-ray energy passes through a rotating object. Stacking 2D cross sectional images builds 3D image.	No external EFR, included in turnkey system
Time of Flight (TOF), Pulse-based Laser Digitizing, Laser Tracking	Time of Flight	Active	Surface	Laser	Optical detection of laser beam pulses	Pulsed laser light is sent to the object, and a portion of that pulse is reflected. Absolute distance to target is calculated based on the time for the pulse to return to the detector.	Center of reflective probe is tracked by laser. EFR using optical targets in the scene and post-processing software
TOF Phase Shift Laser Digitizing	Time of Flight	Active	Surface	Laser	Optical detection of laser light's phase shift	Varying wavelength laser light is sent to object; phase shift of reflected wave is measured to determine object's position and intensity.	Center of reflective probe is tracked by laser. EFR using optical targets in the scene and post-processing software
Dense Stereo Vision Digitizing	Non-destructive	Passive	Surface	None-ambient white light	Optical detection of white light using high-resolution or stereo cameras	A point on the surface is located by analyzing the difference of multiple images of the surface taken by high-speed, high-resolution or stereo cameras placed around a part.	Post-processing software

Benchmark Before You Buy

Benchmarking involves evaluating sample scans and comparing results to known nominal values. It can highlight unpredictable or non-obvious issues, and can help the user gain confidence in a technique and its results. It can also help determine whether additional external reference hardware or software is needed for your specific application.

Marc Soucy, president of InnovMetric, stresses that benchmarking allows a wide variety of software options, plug-ins and add-ons to be demonstrated, that can control digitizing hardware or reduce sample or evaluation time. He suggests that benchmarking should include repeated measurements of a known part before making a system purchase, and recommends benchmarking the digitizing and external frame of reference (EFR) technologies under consideration together.

ders, edges and cracks. They are more robust to ambient light sources, and less subject to noise from object color or luster.

There is a performance trade-off, however, for technologies with a baseline, such as triangulation. Larger baselines are more accurate, whereas smaller baselines exhibit fewer occlusion effects. The laser speckle effect also limits this technique's accuracy on optically rough surfaces.

Fringe-based Projection Techniques

Successive images of fringe patterns are projected onto an object, and one or two high-density cameras capture surface images. Enough fringe patterns are projected until a grid of object coordinates can be formed from intersecting reflections on individual camera pixels (see Figures 13 and 14).

Detailed measurements can be made by taking a series of photos with different stripe pattern widths (phase-shifting). This technique is known as white light time-multiplexed pattern projection.

These close-range measurement techniques offer good accuracy and lateral resolution along two axes, and are fast to measure objects with low-curvature surfaces. Important limitations of fringe techniques, however, are that they lack the dynamic range needed to scan shiny finishes, are slow to measure objects with intricate details, and suffer from occlusion effects, requiring additional shots depending on the size of the object.

Industrial Computer Tomography (CT) Techniques

These close-range, turnkey techniques produce a complete volumetric point cloud of an object, and in some cases, allow porosity and internal defects to be seen. They are very accu-

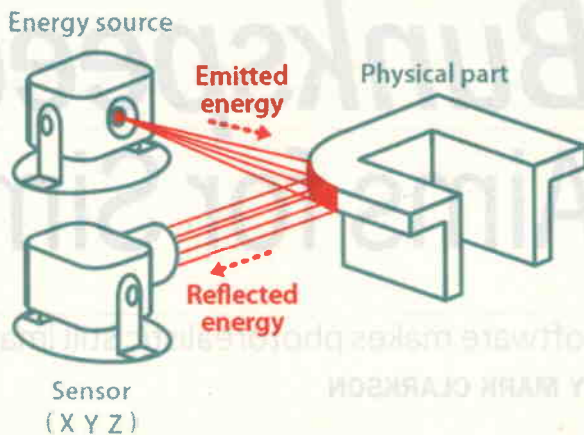


FIGURE 3: The basic concept of high-density, non-contact digitizing.

rate techniques. Unfortunately, CT can be quite expensive, and calibrating and measuring parts made with different materials is a challenge.

Time-of-flight (TOF)-based Laser Techniques

Pulse-based and phase-shift TOF techniques are co-axial technologies with no baseline and therefore no occlusion effects. They are compatible with conventional surveying tools such as GPS, GIS and LIDAR. Their acquisition speeds are suitable for measuring objects such as cars, planes, trains or buildings. One disadvantage of TOF laser techniques, however, is that they are less accurate than close-range techniques.

Passive High-density Scanning

Also known as dense stereo vision (DSV) digitizing, passive scanners capture high-resolution photographs of surfaces lit with high-lumen external or ambient light, instead of radiating light. DSV techniques use multiple cameras and processing software, and are useful for mid-range scanning. They are simple to set up, have rapid measurement times, and some commercial versions provide automated surface matching. Drawbacks include being less accurate than close-range techniques due to occlusion effects, and only working on parts with texture.

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→ National Research Council Canada: NRC-CNRC.GC.ca/eng/projects/iit/3d-metrology.html

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