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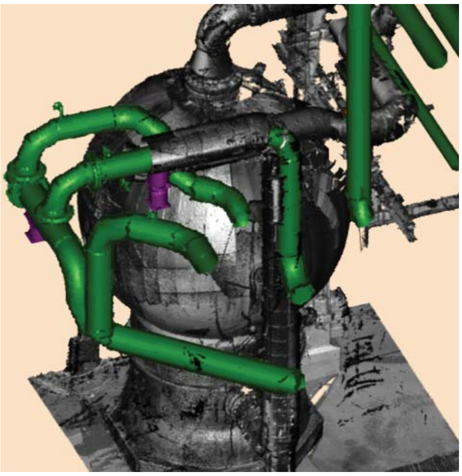
Specifying Laser Scanning Services



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Increasingly, project managers are called upon to employ laser scanning technology. However, little information is available to aid with its specification. This article discusses the basics of laser scanning and the parameters that should be included when specifying these services.

Laser scanning is rapidly becoming a standard technique for process, power and offshore engineering and design projects. Laser scanning has been shown to reduce costs, improve schedules, increase quality and enhance safety — resulting in up to an 80% reduction in project rework — making it an attractive alternative to manual data collection or other techniques.

This article focuses on volumetric laser scanning of structures and buildings, and not laser total stations or other traditional survey equipment or techniques. Its goal is to help project managers gain a better understanding of the basics of laser scanning technology and to learn what specifications are important — without getting bogged down in the hype or in the confusing, and sometimes contradictory, set of hardware and software performance claims. It is possible, with basic knowledge and early preparation, to create bid specifications for laser scanning services that are both practical and which will result in positive project results each and every time.

Laser scanning terminology

A laser scanner is a device that generates spatial information for a spherical volume using a laser measurement device and a steering device. It differs from traditional survey equipment in that it is specifically designed for high data rates and works in complex, unstructured environments. The terms laser scanner, 3D laser scanner, laser camera, 3D laser camera, and light detection and ranging (LIDAR) are generally considered to be equivalent.

A laser scan (or scan) is a single data set collected by a laser scanner for an area. A laser scan from a laser scanner is roughly analogous to a digital picture for a digital camera. A laser scan is sometimes referred to as a point cloud or a cloud of points. This term originates from the point-like appearance of low-density laser scans. Targets are placed in an area to identify a specific known location in the scans.

Registration is the process of integrating multiple laser scans from multiple laser scanner placements into a single central coordinate system. The result is a registered network of laser scans (or registered network). This process is also referred to as stitching or merging.

Laser measurement fundamentals

What is laser distance measurement and how does it work? Put simply, the laser measurement device uses a laser to compute the distance to an object by emitting a laser from a transmitter, which then hits an object and scatters. The laser energy that reflects back in the direction of the transmitter is collected and measured. An important point to understand is that only the light that reflects back is measured. Thus, laser measurements on objects that are shiny, extremely diffuse or at oblique angles to the sensor are difficult, regardless of the technique employed to calculate the distance.

There are two common methods used to measure distance. The first and most common method uses pulses of laser energy (pulse-based); the second uses a phased continuous wave of laser energy (phase-based).

Pulse-based. The most common type of laser measurement uses the time-of-flight of the laser to compute distance. In these systems, a pulse of laser energy is emitted and a clock is started. The clock is stopped when the pulsed laser energy returns to the receiver. The elapsed time is used to compute the distance. Pulse-based systems are relatively simple, with longer distance properties (50–500 m), but relatively low data rates (typically 1,000–20,000 measurements per second).

Phase-based. The second type of laser measurement uses calculation of phase differences to compute distance. In these systems, a continuous beam of laser energy is emitted, but the beam is modulated. The received laser energy is compared to the transmitted energy to determine the phase shift, which is then used to calculate distance. Phase-based systems are more complex, with shorter distance properties (typically from 50–60 m), but much higher data rates (100,000–500,000 measurements per second).

Given that there are at least two methods to determine distance, which should you use? The answer depends on your needs. If you require relatively sparse data at long distances, then pulse-based is a good technology to use. It is most typically used for civil engineering, such as quarries and landscape features. If you require dense data at shorter ranges, then phase-based is the most appropriate technology. It is most typically used for building interiors and exteriors, process facilities, and other dense structures. This type of scanner is also good for performing large projects in short amounts of time due to its fast data collection rate.

Laser scanning service specifications: Which ones are important?

A typical laser scanner has a long list of technical specifications. Laser power, spot size, reflectivity responses, linearity, and a host of other parameters are included. Many of these specifications are purely informational and do not readily equate to the performance of the laser scanner for a project. Other important specifications are not related to the laser scanner itself, but to the service provider doing the scanning.

For specifying laser scanning services, parameters should include eye safety, measurement accuracy, spatial resolution, calibration (including repeatability and variability), temperature and humidify compensation, and data registration.

Eye safety. Lasers with wavelengths in the visible spectrum are typically used to obtain a Class II eye safety rating (Box). Unfortunately, these suffer from increased noise due to ambient light, and measuring objects with a complementary color can be difficult. For example, if you have a project with red equipment and pipes, avoid laser scanners that use a green laser and, instead, employ laser scanners that use red or infrared lasers. Near-infrared lasers are typically selected because they alleviate many ambient noise issues (erroneous measurement due to environmental conditions), but unfortunately even low power devices are Class III devices due to the nature of laser safety regulations.

So, how do you use this information to create a specification for your project? First, be sure that the laser scanning service company can prove that it has satisfied U.S. law with the classification of its equipment by asking to see its laser safety information. Every manufacturer is required to correctly identify its equipment and should be happy to comply with any request for verification of classification. Second, be sure that the service company that will use the laser equipment is well trained in its use and has a formal safety program in place to ensure compliance with all OSHA and CDRH regulations. Treat laser scanning as you would other craft professions. You do not

Understanding Eye Safety

In the U.S., laser devices are regulated by the Center for Devices and Radiological Health (CDRH), a division of the Food and Drug Administration (FDA). The CDRH, in conjunction with ANSI and OSHA, publishes standards for the safe use of laser devices. These standards create four broad classifications of lasers based on their potential for harm and the precautions required to prevent harm. A Class I device is always considered to be the best class, since it requires no precautions by the user to be considered safe to use. A Class II device is, by definition, a visible spectrum laser. However, a visible spectrum laser is not guaranteed to be Class II, depending upon its output power. A Class II device requires a few precautions for safe use, including the concept that the eye will protect itself by blinking if the laser exposure is less than 1/4 second. Class III is reserved for low-power lasers outside of the visible spectrum and for visible lasers past a certain power rating. As in Class II, an infrared laser is not necessarily Class III — certain wavelengths of the infrared spectrum are actually Class I.

These laser classifications provide controls and procedures for safe use of laser devices. No matter what the classification of the laser scanner, if the device complies with the CDRH guidelines and is used in the prescribed manner, it is eye safe.

have to understand the intricacies of the safety policies and regulations you just need to be sure that they are being met and that a safe result will occur.

Measurement accuracy. A typical goal of a laser scanning project for an engineering application is to provide accurate measurement information. This allows new designs to be inserted into the existing facility by providing precise locations of tie-ins and interfaces between the new designs and existing equipment. This can be accomplished by specifying the measurement accuracy.

Measurement accuracy is the ability to generate physical dimensions using the laser scan data that are correct metrically to within a stated tolerance. Simply stated, this provides the ability to measure a physical object and get the correct size and location in space using the data delivered from the laser scanner.

Measurement accuracy is specified as a ± quantity, usually in inches. This single parameter encompasses many other specifications into a simple, easy-to-measure and easy-to-evaluate specification that can alleviate much confusion. For practical purposes, the lower limit of this quantity is ±1/4 in. However, it is possible to achieve ±1/8 in. over specific volumes. If a service provider offers better than this, ask for verifiable proof and a real-world demonstration before you believe it on faith.

While a laser scanner specification sheet may include many other parameters, such as point accuracy, spot size or maximum range, it is not necessary to include these when the measurement accuracy of the data is specified. Ask yourself this, when you specify a traditional survey, do you ever read the specification sheet on the total station? Typically not, you specify what you want and let the service provider figure out the rest.

Spatial resolution. By setting a specification for measurement accuracy, you have also effectively set a specification for spatial resolution. Spatial resolution is the spacing between individual measurements in the laser scan. Since a laser scanner is an angular device, this spacing varies linearly with distance from the scanner. Therefore any specification of spatial resolution must also be accompanied by a range value, such as 1/4 in. at 60 ft, or a limit for the entire scan (no worse than 1/4 in.).

There is a close link between spatial resolution and measurement accuracy. Without a proper scan resolution, it is not possible to accurately measure the shape and size of physical objects. Take, for example, measuring the width of a column (Figure). Since laser scan data is digital, we are working with the locations of individual measurements. Notice what happens at the edges if the measurement spacing was such that the edge of each side of the column was just missed by the laser scan. This means that the first measurement of the column will be inside the leading edge of the column by a distance of one measurement. When the column is measured, the result will be the real dimension — 2* spatial resolution. The only way to achieve a specified measurement accuracy would be using a spatial resolution of 1/2 the measurement accuracy. Therefore, if you specify a measurement accuracy of ±1/4 in., then a spatial resolution of ±1/8 in. must also be specified.

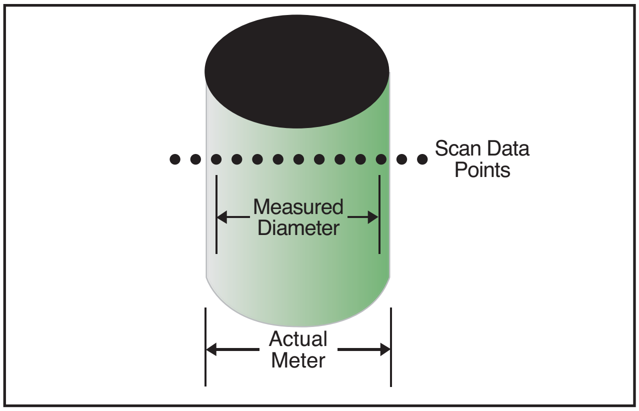

Figure. There is a close link between spatial resolution and measurement accuracy. Without a proper scan resolution, it is not possible to accurately measure the shape and size of physical objects.

Calibration. Laser scanners are much more complicated than a total station or other survey instrument. Every laser scanner is a collection of moving parts with optics, motors and electronics. Poor calibration will result in inconsistent and incorrect project results along with significant headaches. To achieve a specified measurement accuracy and spatial resolution, proper calibration is required for each project and proof of this calibration should be included in any specification.

How do you evaluate calibration? You need not understand how the equipment is calibrated as this can be a very technical and perhaps even proprietary. Instead, concentrate on the results of calibration testing. Repeatability and variability are two test parameters that can quickly find calibration errors. A calibrated laser scanner should undergo tests in a controlled environment for both of these parameters and the results should be supplied with the project deliverables.

Repeatability. To properly perform a repeatability test, the service provider should take multiple images of a controlled scene and compare the results statistically to determine the amount of difference. A quantitative, statistics-based summary is required to evaluate repeatability — a qualitative assessment is not sufficient. The laser scanner must be repeatable to the tolerance required to make the measurement accuracy specification achievable. The laser vendor can set this tolerance, but it must be defensible.

A Guide to Using and Specifying Laser Scanning Services

The list below provides a reference guide for both specifying laser scanning services and extracting the greatest value from the data.

✔ **Set a goal —** The first and absolutely most important step in specifying a laser scanning project is to understand what you want to accomplish. Don't expect to be satisfied with the results if you ask a service provider to "scan the plant". Work with the service provider before the project to plan the workflow, identify the specific areas of interest, the desired deliverables and manage the expectations of the project team.

✔ **Select a work process —** Understand the work process you intend to use to incorporate laser data into your design workflow. Without a clear plan of action for using the laser data for design, you will not realize the significant cost savings and benefits that are possible. For example:

- Will pipe be field-routed or will routing be performed in office?
- Will design work be performed locally or by distributed global teams?
- Will you work in 3D to design pipe routes or in 2D and convert to models?
- Is the design work already complete and you just want to check it before construction?

✔ **Require proof of Center for Devices and Radiological Health (CDRH) compliance —** Protect yourself. Require proof of compliance with CDRH regulations both for the hardware and for the work process. Request a copy of the service provider's safety program and its safety records. Be sure the laser scanning hardware is correctly labeled and that the classification claimed is backed up with mathematical proof. Eye safety is ensured if the service provider and the laser scanner manufacturer comply with existing regulations.

✔ **Specify the measurement accuracy —** This parameter is determined by your project requirements. It is a function of the engineering requirements and is specifically the absolute metric accuracy of measurements taken of physical objects within the scanned volume. Measurement accuracy should be specified as a plus and minus quantity. A realistic value is ±1/4 in. Be skeptical of accuracy claims that are less than this value.

✔ **Specify the spatial resolution —** Based on your determinations of required measurement accuracy, specify in the bid request the requirements for delivered spatial resolution equal to 1/2 the measurement accuracy. This will ensure the project receives the amount of data required.

✔ **Require proof of calibration —** Proof of calibration against a controlled environment that includes repeatability and variability measurements should be required for every laser scanning project. It is not sufficient to claim that a device is self-calibrating, nor is it sufficient to be given a calibration date or other notice of calibration.

✔ **Require proof of temperature and humidity compensation —** Be sure your laser scanning service provider is using a laser scanner that has been correctly compensated for both temperature and humidity, otherwise you could receive unexpected results.

✔ **Require data registration statistics —** Regardless of the quality of the laser scanner, if the data is not registered into a common coordinate system correctly then nothing can be said about the ultimate accuracy of the deliverable. Registration accuracy can be checked against your specifications by requesting a registration report that provides a Chi2 test for fit quality. Without this statistical assurance there is no way to evaluate the quality of the deliverable until you find problems while working with the data on your project. Also ensure that the service provider's registration work process can properly address both rotation and propagation errors.

✔ **Require references —** Do not be overawed by technology. In selecting a service provider, experience matters, so check for references.

- How many projects have they executed?
- Have they ever worked in your industry before?
- What reference projects are available?

Variability. This is a measurement of the quality of the calibration across the entire field of view of the laser scanner. A variability test is performed by taking scans of a controlled scene from multiple viewpoints, but with a large degree of commonality. The scanner setups should be as dissimilar as possible, while still maintaining common coverage. Measurements are then made in the data between known targets in the scene and compared between scans. If a scanner is well calibrated, then the measurement results between the different scans should be within a specified tolerance. This tests whether a physical object will be the same size when measured in multiple images. Without this information, a key quality control checkpoint will be missing.

Temperature and humidity compensation. Temperature plays a large role in the measurement accuracy. The wavelength of a laser varies with temperature, so it is essential that any laser scanner be carefully temperature controlled and compensated. The effect of changes in temperature on a laser measurement system that has not been correctly compensated can be extreme, potentially introducing inches of error in the output. For example, if a laser scanner that was not temperature-compensated scanned a room while the temperature was changed in increments of 5°F, until there is a 30°F temperature change, the data would show a "Russian Doll" effect in which successive laser scans would stack within one another or be warped between scans. To avoid this issue, simply specify that the laser scanner be temperature-compensated.

Another aspect of temperature is the ability for the laser scanner to operate in intense temperature extremes, especially high heat. In process facilities, it is not uncommon to find environments that are 110°F or above. If this matches your situation, ensure that the laser scanner is designed for these types of environments or it may prove unreliable or unstable. Including this in the laser scanning service specification can save you problems later.

Humidity can also affect laser scanner performance. Humid air is denser, and affects the laser measurement. Most equipment is rated to 95% non-condensing humidity, but some areas exceed this, such as Houston in August. If scanning is required in areas of high humidity, ensure that this is included in the specification.

Data registration. When specifying measurement accuracy, you are also implicitly specifying registered network accuracy. Regardless of the quality of the individual laser scans, if they are not placed into the global coordinate system properly, the resulting measurement accuracy will be poor.

Registration accuracy does not appear on any laser scanner specification sheet. This is because it is the work process used by the service provider in conjunction with the laser scanner that drives registration accuracy. Any experienced provider will have a work process that correctly addresses registration issues and should be able to provide proof for the accuracy of the registered network.

So, what is an appropriate parameter to use to evaluate the quality of registration? A commonly specified parameter for registration accuracy is the Chi2 statistic, which is a well-known and accepted statistical measure of the "quality of fit" for a survey network and has been used in traditional survey practice for many years. The result of the Chi2 test is a simple pass or fail criteria. If it passes, then the registered network statistically fits to the tolerances required; if it fails, then it does not. This simple and unambiguous test should be specified to mitigate the risk of inaccuracies and evaluate deliverable quality. Additionally, ensure that the data registration technique used by the service provider can address the following data registration errors.

Rotation error. This is the worst kind of error that can be introduced into registration. Rotation errors vary with distance from the scanner center and can be difficult to diagnose. This type of error is typically introduced through manual registration techniques or poorly placed targets.

Error propagation. This is the accumulation of small errors from scan to scan as network registration takes place. While measurements within each scan may be within a 1/4-in. specification, if there is a 1/4 in. between each scan, this can translate into a potential 25 in. error between scan 1 and scan 100.

References. Do not be overawed by technology, select a service provider that has significant and relevant industry experiences and good references. This can have a major impact on both the efficiency of the laser scanning and the quality of the delivered data. Specify that the provider supply the total number of projects executed, relevant industrial experience and reference projects.

Tangible benefits

All project stakeholders — owner-operators, engineers, designers, maintenance personnel, project managers and equipment vendors — are likely to find that laser scanning can provide a significant return on investment for any project. Early adopters have found it to be safer, faster, and more accurate and transportable than any other option for capturing and sharing dimensional details of existing facilities. Among the many tangible benefits are:

- reduced costs resulting from quickly capturing as-built dimensions; eliminating construction rework and field changes, and shorter outage durations
- schedule optimization by reducing time spent in plants collecting data; improving design efficiency; enabling prefabrication of components; minimizing construction durations, and less rework
- quality enhancements from greater accuracy and precision that improves engineering designs
- safety improvements by reducing the exposure to potential hazards within the plant environment. CEP

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