White Paper

Inside Trimble TX8 - Deep Dive into Lightning Technology

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ABSTRACT

With the introduction of next generation Trimble® Lightning technology, users can benefit from the positive aspects of both time-of-flight and phase-shift technologies with Trimble's TX8 3D laser scanner. This new generation, patented time-of-flight technology enables ultra-high speed data capture of one million points per second while maintaining high accuracy over the entire scan range, opening new possibilities to accomplishing more with a single scanner. The purpose of this paper is to:

- Demonstrate the benefits of the Trimble TX8
- Explain how Trimble Lightning technology advances time-of-flight measurement to collect clean, accurate data, faster than ever
- Provide detailed information on performance, accuracy and precision concepts applied to Trimble TX8

We faced the challenges of 3D scanning. And we solved them. Here's how.

TECHNOLOGY THAT transforms

Trimble

Many industries depend on 3D scanning to manage complex projects, enabling them to get jobs done quickly and accurately. The challenges of 3D measurements are clear. The Trimble TX8 3D laser scanner is changing the way the industry looks at 3D. It captures high quality scans at exceptionally high speeds even as it delivers superior accuracy and range. So it enables users to handle a wide range of projects with the same, powerful solution, making it the best value on the market.

INSIDE TRIMBLE TX8

When it comes to 3D laser scanners there is no one size fits all. Generally, 3D laser scanners are defined by two types of measurement technologies, phase-shift and time-of-flight. Phase-shift is usually associated with high accuracy at close range and fast scan speeds approaching one million points per second. Time-of-flight, on the other hand, has been used for longer range applications that require more consistent accuracy over the entire scan range, but at the cost of significantly slower scan speeds.

The patented Trimble Lightning technology combines the benefits of both technologies. The details about the different measurement technologies and published specifications show the true value of the Trimble TX8 and its innovative time of flight technology.

PRACTICAL BENEFITS OF TRIMBLE TX8

High-end performance and productivity

The Trimble TX8 is capable of attaining published accuracy, range and speed simultaneously. This provides unmatched overall performance for capturing high-density 3D point clouds. At one million points per second, the TX8 achieves < 2 mm precision over the full scan range of 120m with standard scan times of only three minutes. A high precision scan option is capable of < 1 mm over 80m. An optional upgrade is also available to extend the scan range to 340 m. The ability to achieve published range noise and accuracy specifications at maximum scan speed makes the Trimble TX8 the most productive 3D laser scanner in the world. Other scanners may advertise similar scan speeds, but in fact must reduce scan speed in order to achieve published specifications. Below are examples of the range and accuracy the TX8 can achieve at one million points per second.

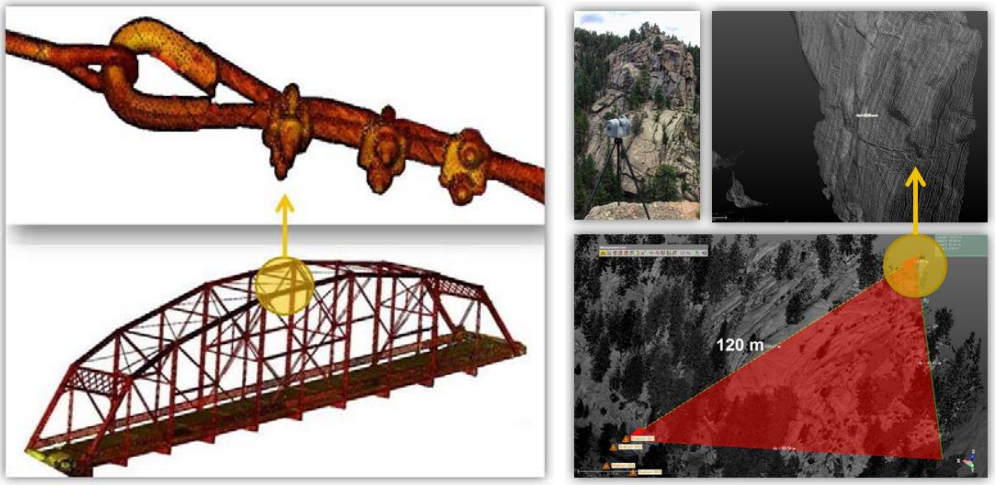


Figure 1: Bridge overview and detail. Rock face photo overview and detail

Versatility

Historically, the strengths and weaknesses of both phase-shift and time-of-flight scanners required the purchase of both types of scanners to support a full range of applications. The Trimble TX8 now combines the strengths of both technologies—including speed, accuracy and range—so scanning service providers can bid and successfully complete more diverse projects with one system.

Typical applications include civil survey, bridges, urban areas, architectural renovations, commercial construction, plants, mining and quarries, deformation analysis and historic preservation and restoration. Phase-shift scanners are limited to short or mid-range applications and are not suited for civil survey applications that require longer distance and greater accuracy over the full scan range. Comparable, longer range time-of-flight scanners have a limited field of view or slower scan speeds, making them impractical to use in an indoor environment where overhead data collection and fast scan times are essential to be productive.

Below and throughout this paper, you'll find examples from several of the different applications for which the TX8 is used.

Figure 2: Colored point cloud of a 14th century castle, Chateau d'Ainay-le-Vieil

Designed and built for demanding environments

The Trimble TX8 has a very dependable, rugged design with an IP54 rating and protected mirror that is unaffected by bright sunlight. Some manufacturers don't have an Ingress Protection rating for dust and water protection, which makes the scanner susceptible to damage when operating in tougher environments such as mines and quarries, or simply any dusty or rainy environment.

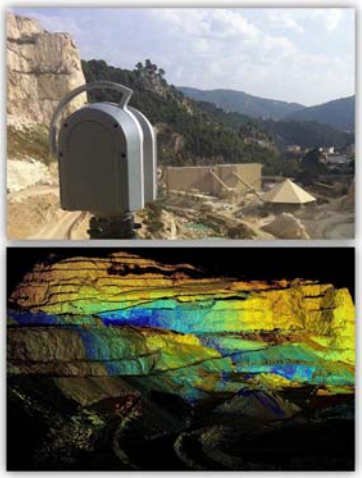


Figure 3: Quarry photo and point cloud of long range scan

Figure 4: Plant environment scan

Trimble Lightning technology also makes the TX8 less susceptible to variations in surface types and atmospheric conditions. Distance measurement is a function of the velocity of light in the atmosphere and the velocity of light depends on the refractive index of air, temperature, pressure, and humidity. The EDM technology uses the Atmospheric Correction feature to apply corrections to the distance measurement, expressed in Parts per Million (PPM), according to the atmospheric conditions.

The scanner also has an eye-safe Class 1 non-visible laser that can be used in busy public places and a scan pause function that makes it possible to prevent unwanted noise in high traffic areas. With the TX8, it's possible to get high-quality results in even the most demanding environments.

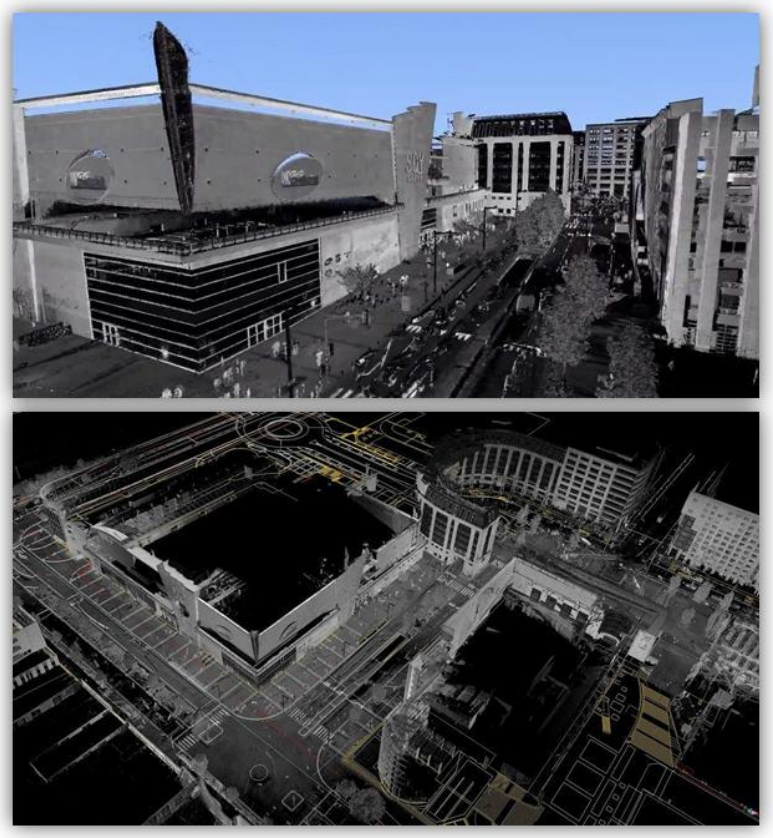


Figure 5: Urban environment, point clouds

Ease of use

The Trimble TX8 user interface is extremely intuitive and easy to learn with little or no training for immediate productivity gains. The touchscreen display and one-button scanning make data capture easy and efficient. Scan options can easily be selected to adjust resolution, precision and range to support any application or project requirement.

The Trimble TX8 focuses on laser scanning for optimum productivity in the field. Operators are not required to follow a more complicated survey workflow required by more expensive time-of-flight scanners. The TX8 can support a basic survey workflow or be used in conjunction with a Trimble S Series total station. The TX8 design objective was to set a new standard for performance and ease of use for greater productivity in the field and the back office.

Quick production of deliverables

The Trimble TX8 streamlines work in the office with clean, low-noise data, which reduces the time needed for processing. Data from the Trimble TX8 loads directly into Trimble RealWorks® for automatic scan registration, data management, analysis and advanced modeling. It also provides efficient data flow into Trimble SketchUp®, Trimble EdgeWise and other popular CAD programs. Customers can also publish projects to make them accessible from Internet Explorer with Trimble Scan Explorer. No license is required to freely share the project data. The Trimble TX8 and Trimble software provide a complete scanning solution to meet a wide range of project requirements.

Figure 6: Trimble TX8 scans modeled in SketchUp for a building renovation project.

TIME-OF-FLIGHT OR PHASE-SHIFT MEASUREMENT?

Time-of-flight is a measurement principle based on emitting a light pulse, which travels at the speed of light, and then measuring the travel time. By accurately measuring when the pulse leaves the laser and returns, you can use the known speed of light and the travel time to calculate the distance to the object from which the pulse was reflected back. (Distance = (Speed of Light x Time-of-flight) / 2).

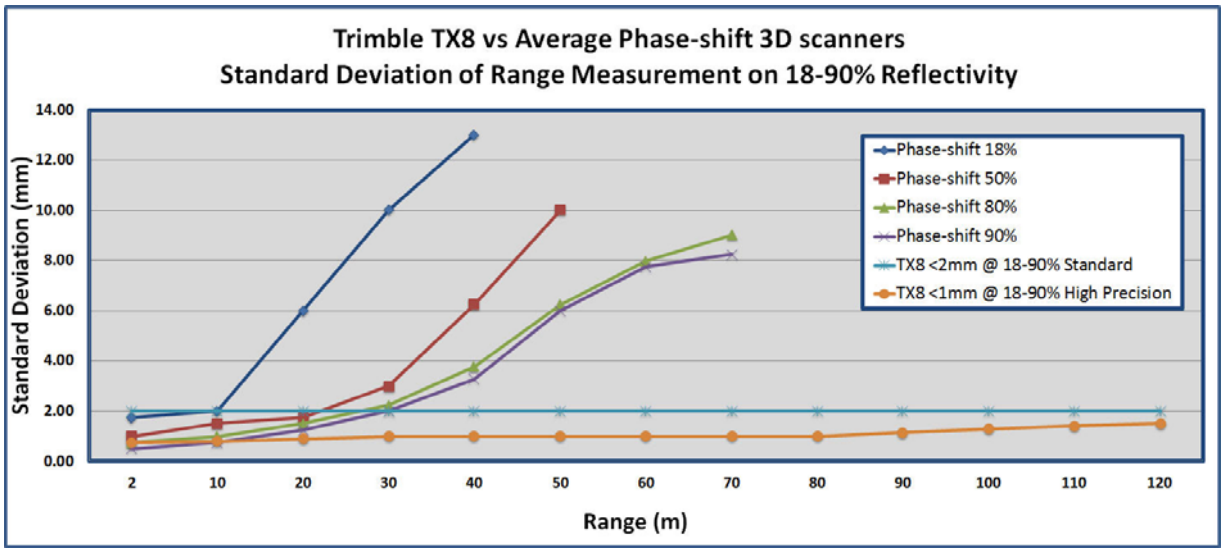
Phase-shift 3D scanners emit a constant laser beam into multiple modulations and compare the phase-shifts of the return. The scanner then uses phase-shift algorithms to determine the distance, based on the unique properties of each individual modulation. The multiple modulation frequencies are used to achieve a certain accuracy and to resolve range ambiguity. (Distance = Phase-Shift / (2π x Modulation Frequency)).

Trimble TX8 Lightning Technology

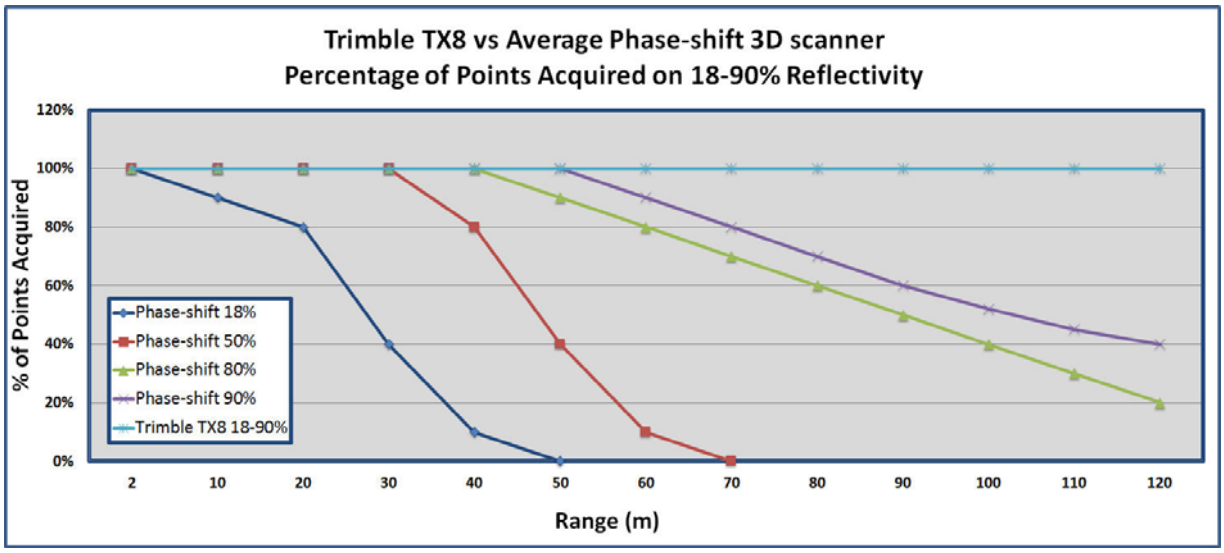
The Trimble TX8 3D laser scanner represents the next generation in time-of-flight 3D laser scanners. At the core of this advancement is the patented Trimble Lightning technology, a new EDM (Electronic Distance Measurement) able to measure at the ultra-high speed of one million points per second without compromising performance in terms of range, sensitivity and accuracy.

A key point when comparing scanning speed is to consider effective speed, not peak speed. Other scanners may achieve similar scan speeds, but with compromises on range, sensitivity or accuracy. With phase-shift 3D laser scanners, the percentage of points acquired at maximum range decreases and the precision of range measurement is impacted more rapidly over the full scan range.

The graph below shows the standard deviation of range measurement on different albedos (18 to 90%) when comparing the Trimble TX8 with average results of phase-shift 3D laser scanners in an outdoor environment.



The graph below shows the percentage of points acquired on different albedos (18-90%) when comparing the TX8 with average results of phase-shift scanners.



Expected productivity gains in the field are often lost due to missing data or longer post processing requirements and phase-shift scanners must significantly lower the scan rate to achieve these results. The Trimble TX8 offers a huge productivity benefit because the entire data chain has been tuned at the same speed level; that includes raw distance measurement (laser source, analog and digital electronic designs), metrology compensations, data management (compression, storage) and on-board data visualization. The Trimble TX8 achieves the results above while maintaining a scan speed of one million pts/sec.

Comparative benefits

Below is a summary of the benefits the Trimble TX8 has over phase-shift 3D scanners and over higher priced time-of-flight 3D scanners.

Trimble TX8 vs. Phase-shift Scanners

- Higher precision and accuracy over full scan range
  - Some phase-shift scanners often publish range noise and accuracy for distances that are as much as 80% less than the published maximum range
  - Range noise increases significantly over the full scan range
- Better range, accuracy and quality achieved with faster scan times
  - Some phase-shift scanners must reduce scan speed up to 90% to achieve published range and performance specifications
  - On some models, maximum range is only achieved on 90% reflective surface
- Faster, cleaner scans increase productivity in the field and office
- More dependable rugged design with IP54 rating
  - Some lower priced phase-shift scanners have no Ingress Protection rating for dust and water protection

Trimble TX8 vs. Other Time-of-flight Scanners

- Easiest overall scanning workflow compared to complex workflow and scan parameters
- Better range, accuracy and quality achieved with faster scan times
  - TX8 120-340m vs. typically 120-270m
  - Constant precision over full scan range
  - No wavy surfaces and minimal ghost points between surfaces
  - Faster scan times achieve comparable accuracy
- TX8 scan times are 2 min, 3 min, 10 min vs. typically 3.25 min, 6.47 min, 27.04 min
- Better FOV at 317°x360° vs. typically 270°x360°
  - For overhead scanning, the handle must be removed from some time-of-flight scanners
- Faster, cleaner scans increase productivity in the field and office
- Better ROI with up to $30,000 price difference

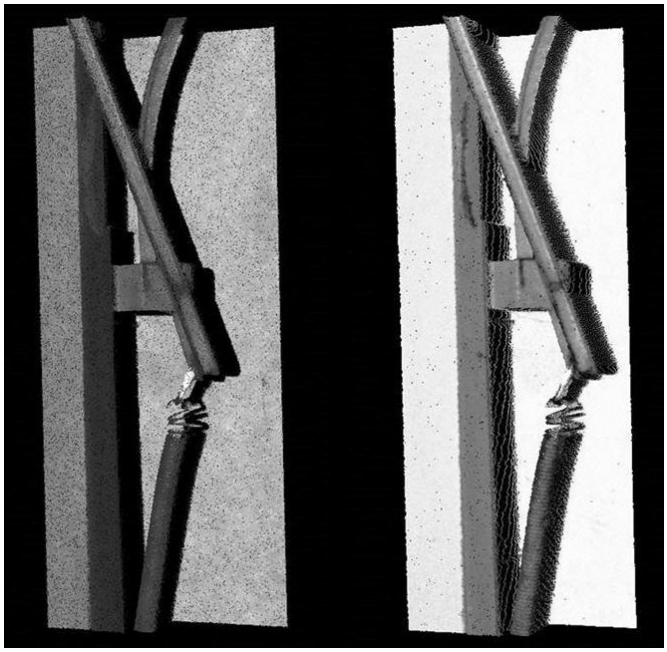


Figure 7: Image above shows objects scanned with TX8 on the left and another time-of-flight 3D scanner on the right, with ghost points between the two surfaces.

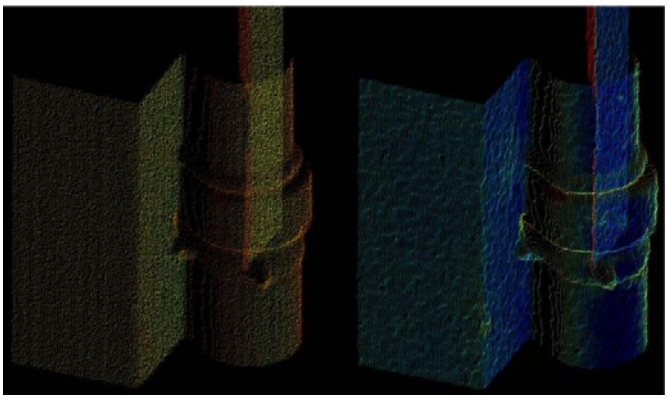


Figure 8: Image above shows objects scanned with TX8 on the left and another time-of-flight 3D scanner on the right with irregular, wavy surfaces.

PRECISION AND ACCURACY OF TRIMBLE TX8

Specifications related to measurement results are made in consideration of international standards such as ISO "Guide to the Expression of Uncertainty in Measurement" [1], ISO VIM "Vocabulary of Basic and General Terms in Metrology"[2], and NIST Technical Note 1297 [3].

Published specifications

Below are the published specifications Trimble declares for precision and accuracy of distance measurements (range noise and systematic error) and angular measurements (angular accuracy). It is important to review the notes related to performance specifications when considering any scanner. You may find the scan speed must be reduced in order to achieve the published specification, or you may find the specification is only valid for a small, optimum range of surface reflectivity. In addition, manufacturers may limit accuracy specifications to a shorter scan range and not the maximum range they advertise.

Range noise[1]	<2 mm from 2 m to 120 m on 18–90% reflectivity in Standard mode
	<1 mm from 2 m to 80 m on 18–90% reflectivity in High Precision mode
Range systematic error[1, 2]	<2 mm
Angular accuracy[1]	80 µrad

1 - Specification given as 1 sigma

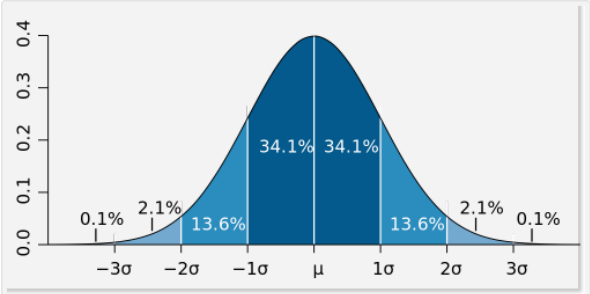
2 - At distance of 1.5m to 100m for albedo >20%

It is important to understand the difference between precision and accuracy when analyzing scanner specifications and performance.

- Precision is a description of random errors or the closeness of two or more measurements to each other (e.g., the thickness of point cloud on a surface). The range noise specification relates to precision.
- Accuracy is a description of systematic error or the closeness of a measured value to the true value (e.g., the trueness of measuring a known target). The range systematic error specification relates to accuracy.

Precision

For the range noise specification, the tolerance value is given as one standard deviation or one sigma (1σ) only. Repeated measurements with this kind of random noise give a normal distribution around the mean value, as shown in the graph below.



The probabilities of a value lying within 1-sigma, 2-sigma and 3-sigma of the mean for a normal distribution.

This means that 99.7% of the points are within +/- 3σ of the mean value. If there is no systematic error, then this means value will also correspond to the true value.

Accuracy

Accuracy refers to the errors that cannot be removed by averaging. The TX8 scanners go through a rigorous calibration procedure to minimize these errors; however there is always a residual error that will remain. These residual errors can come from many different sources. We therefore express these errors as a Combined Uncertainty (Uc) as defined in [2] which takes into account all of the different sources of error. The systematic error over all scanning angles and ranges is considered to have a normal distribution. In this case we can express the Uc as a one sigma (1σ) error. This means that 99.7% of the points are within +/- 3Uc of the true value.

Distance Precision and accuracy applied to TX8 scans

Below are the results you can expect on distance measurements with the Trimble TX8.

- **Standard precision mode:**
  - Range noise is <2 mm with scans from 2 m to 120 m on 18–90% reflectivity
  - Systematic error is <2 mm from 1.5 m to 100 m on >20% reflectivity
  - So, total single point error is $\sqrt{(2^2+2^2)}=2.8$ mm

  Means: probability that true position is contained in a range of

  - ± 2.8 mm around one single measurement (one point) is 68.3%
  - ± 5.7 mm around one single measurement (one point) is 95.5%
  - ± 8.5 mm around one single measurement (one point) is 99.7%

- **High precision mode:**
  - Range noise <1 mm with scans from 2 m to 80 m on 18–90% reflectivity
  - Systematic error is <2 mm from 1.5 m to 100 m on >20% reflectivity.
  - Total single point error is $\sqrt{(1^2+2^2)}=2.2$mm

  Means: probability that true position is contained in a range of
  - ± 2.2 mm around one single measurement (one point) is 68.3%
  - ± 4.5 mm around one single measurement (one point) is 95.5%
  - ± 6.7 mm around one single measurement (one point) is 99.7%
- **Using reference spheres fitted in Trimble RealWorks:**
  - If there are sufficient points (>80) on the sphere then the range noise contribution to the sphere center position will become negligible.
  - Therefore only the systematic error of 2mm is to be considered

  Means: probability that true position is contained in a range of
  - ± 2 mm around center of fitted sphere is 68.3%
  - ± 4 mm around center of fitted sphere is 95.5%
  - ± 6 mm around center of fitted sphere is 99.7%

Quality assurance and validation of performance

The Trimble TX8 goes through a strict manufacturing process to ensure each scanner is built and certified to the highest standard. The order of assembly and method of construction is tracked throughout the production line to ensure each scanner is built following the same guidelines.

Figure 9: Sub-assembly of parts

Figure 10: Final assembly and balancing

After assembly, environmental stress is placed on the scanners to induce a state in which the mechanical components stabilize. This is done inside thermal chambers, where units are brought to extreme hot and cold temperatures over the course of several days.

Figure 11: Thermal chamber to induce environmental stress with extreme temperatures

Subjecting units to extreme temperatures emulates the environmental conditions under which they will operate––a necessary step prior to calibration. If scanners were calibrated immediately after production, the calibration would be lost shortly after the units were exposed to normal operating conditions in the field. Extreme temperature fluctuations cause mechanical components to settle into a more stable condition conducive to sustained calibration.

Each scanner has unique angular and linear characteristics. Instruments must be adjusted and calibrated at various stages to eliminate errors in measurement. Collimators are used for alignment and angular measurement and scanners are calibrated inside thermal chambers to ensure performance at the specified temperature range of 0°C - 40°C.

Figure 12: Thermal chamber overlooking one of the calibration rooms

Validation tests are performed in a controlled environment using a network of targets with different reflectivity to check various angle and distance measurements. The targets are located at known positions to confirm range systematic error, range noise and angular accuracy, all to ensure the system is operating within published specifications. All production units are tested and validated on this network. Trimble implements quality control measures to ensure TX8 scanners achieve optimum performance and reliability when they leave the factory.

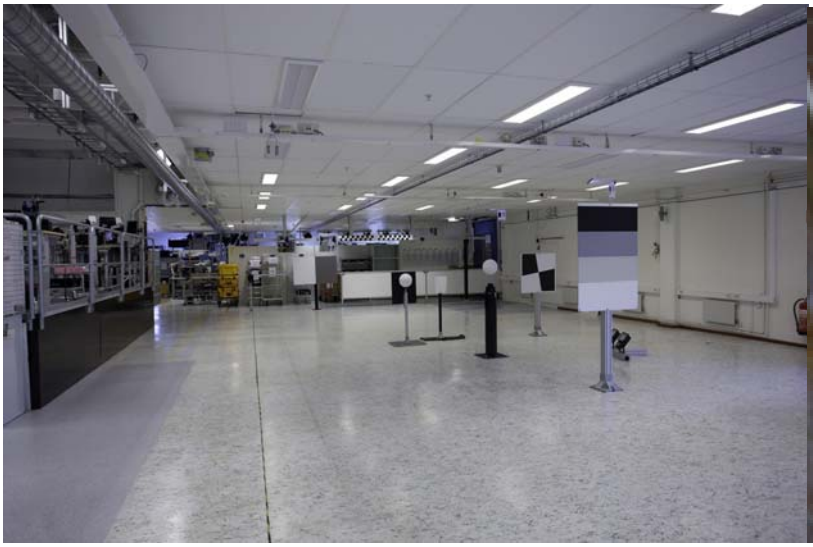


Figure 13: Calibration room for final validation test

Figure 14: Long- range distance test

ADDITIONAL INFORMATION ON TRIMBLE TX8 PERFORMANCE

High Precision

High Precision scans are four pass scans that are longer in duration, but deliver greater precision when processed in Trimble RealWorks using smart averaging algorithms. The merged scan will be about the same size as a standard scan with approximately half the range noise. To compare standard and high precision results, check the standard deviation of geometry fit to the point cloud in RealWorks.

Temperature effect on performance

The Trimble TX8 is not calibrated outside of the published temperature range of 0-40° C, so no performance specification can be guaranteed when a unit is operating outside of that temperature range. Scan operation is not locked when scanning outside the temperature range, but a warning is displayed at the beginning of a scan. Trimble recommends stabilizing instrument temperature within 0-40°C to achieve optimum results. Stabilization is reached when internal temperature does not change more than 1°C for 10 minutes. The temperature can be checked with the diagnostics feature.

Surface reflectivity and sunlight

The strength of the Trimble TX8 return signal depends on the reflectivity of the diffusing surface (e.g., a low level return for lower reflective surface or high level return for higher reflective surface). Sunlight has no impact on surface reflectivity and no negative effect on the TX8 laser, data capture or accuracy, under most conditions. The only impact from the sun is when a small portion of a scan is measured directly into the sun (e.g., scanning the corner of a building while the sun is directly in the path of the area being scanned). Parasite points can appear in that instance, but they are generally filtered out of the scan.

Point spacing and position accuracy

Point spacing has no effect on position accuracy. Accuracy and precision do not increase or decrease based on the point spacing of the preview, level 1, level 2, level 3 or extended scan modes. Point spacing is important when considering the density of point cloud required to effectively capture a simple or complex object. When selecting a scan mode, consider the distance of the scanner from the object and the number of scans that will be taken. If multiple scans are taken in proximity to one another to get different perspectives of an area of interest, it may be possible to achieve sufficient density from overlapping lower level scans. For example, in a complex area of a plant or building, three level 2 scans may capture more overall detail than one level 3 scan.

CONCLUSION

The Trimble TX8 3D laser scanner with advanced Trimble Lightning technology offers the perfect combination of speed, range and accuracy to support a wider range of applications with one system. When combined with Trimble RealWorks, Scan Explorer, and integrated with Trimble SketchUp, Trimble EdgeWise and other popular CAD programs, customers have a complete integrated scanning solution to collect, manage and analyze complex information faster and easier, making them more productive, efficient and profitable.

REFERENCES

[1] JCGM 200:2012 International vocabulary of metrology – Basic and general concepts and associated terms (VIM) 3rd Edition. 2008 version with minor corrections.

[2] JCGM 100:2008 Evaluation of Measurement Data – Guide to the expression of uncertainty in measurement (GUM). GUM 1995 with minor corrections.

[3] NIST Technical Note 1297. 1994 Edition – Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.

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