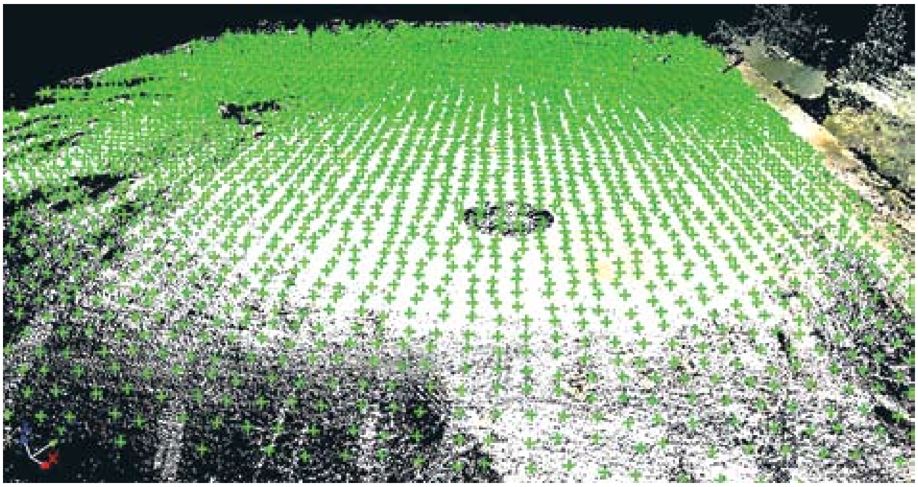
Accuracy of Scan Points



▲ In practice, users often select many individual scan points for creating map deliverables from high-definition survey data. Algorithms can do this automatically.

The main distinction of a high-definition survey is its high point density. A laser scanner can quickly blanket the scene around and above itself with closely spaced, reflectorless shots. So why worry about the accuracy of a single scan point?

The reason is that *users routinely select a large number of specific, single points from scan data to directly make the map, extract distances, etc.* Sub-groups of scan points are also often converted into geometric models, linework, and surfaces, but that's only part of the process.

This article focuses on understanding the accuracy of individual scan points. The accuracy of a single scan point is not just about the scanner—it's equally about scanning software, as this is where users select individual scan points for map making, etc.

Instrument Error

The positional accuracy of a scan point, just as for points gathered by a total station, is based on its three error (or "uncertainty") components:

1. error in the range (distance) measurement,
2. error in the vertical angle measurement,
3. error in the horizontal angle measurement.

The positional error, E, is the square root of the sum of each error component squared.

$$E = \sqrt{(\Delta X^2 + \Delta Y^2 + \Delta Z^2)}$$

ΔX = horizontal angle error
ΔY = range error
ΔZ = vertical angle error

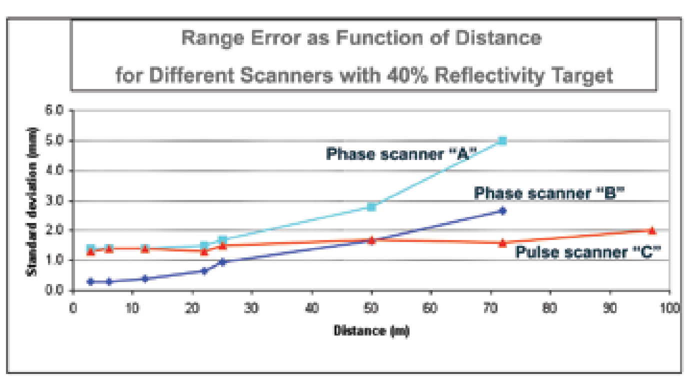
Range Error

The range error of a scan point is the arithmetic sum of its systematic error component and its noise/repeatability component. Manufacturers also often characterize a scanner's range error as a function of (a) an object's distance from the scanner, (b) an object's surface reflectivity, and (c) scan speed.

Function of Distance: Unlike total station specs that state range error as a function of distance in "ppm" format, scanner specs rarely include a ppm value. Instead, they usually state range accuracy at one specific, common usage distance. Due to their commonly close range use (<300'), high-accuracy, pulsed scanners exhibit little influence in range errors from increasing distance within this range. High-accuracy, phase-based scanners, however, can display noticeably increasing range error with increasing distance. Even though phase scanners may be able to collect data out to 200' or so, owners of such scanners often say that they don't use scan data beyond about 35' to 125' away, depending on accuracy requirements

Function of Surface Reflectivity: Range error for both pulsed and phase-shift scanners depends on an object's surface reflectivity. For example, white surfaces produce less noise (hence less range error) than dark surfaces. Scanners can vary significantly from one vendor to another in "range accuracy behavior" for white, black and gray surfaces.

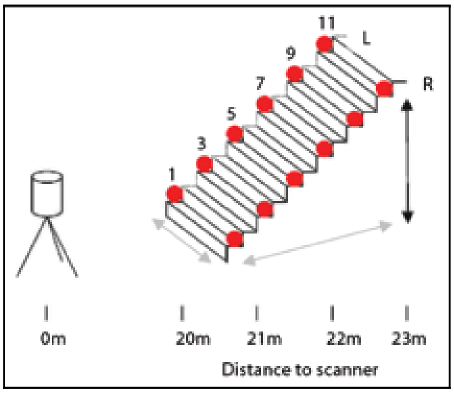
Function of Scan Speed: Phase-based scanners suffer range accuracy degradation as scan speeds are increased; accuracy specs are usually quoted at the lowest scan speed only. Since phase-based scanners are typically used in high accuracy applications (e.g. ¼" or better), users are often unwilling to give up accuracy in exchange for higher density and scan speed. Even for phase scanners that can capture >500,000 pts/sec, users



◀ Scanner range error increases with distance; errors increase at different rates for phase scanners and pulsed scanners —*Image courtesy: i3Mainz* most always operate at the ~125,000 or ~250,000 pts/sec menu option, as files sizes are also smaller when using lower speed settings.

Angular Measurement Errors

Achieving accurate angular measurements of a moving mirror is not easy, yet point positional error depends heavily on the absolute angular error for both vertical and horizontal angle measurements. Angular measurement accuracy specs for scanners today range from



▲ Staircase test set-up used for determining important angular errors in scanners—*Image courtesy: i3Mainz*

a group in the 6 to 12 arc seconds band to much higher (e.g. >100 arc seconds) for very long range, mining scanners. At 165' range with 12-second angular accuracy, the absolute error for each vertical and horizontal angle measurement is only 1/8" (3mm) for a beam hitting the surface at a good angle-of-incidence.

Despite the fundamental importance of angular accuracy, some scanner manufacturers still do not include angular error specs on their data sheets! Instead, some include "angular resolution," as this is generally a very small number (but misleading). However, good surveyors know that "accuracy" and "resolution" (ref. *Professional Surveyor Magazine*, Jan. 2005, "Terminology" pp. 26-31) are two different things and "accuracy" drives deliverable requirements.

Spurious Scan Points

Laser scanners, like reflectorless total stations, can record points that may not represent what the operator is actually trying to capture. Spurious points can result from the following factors.

Sun-caused: Scanners with highly sensitive detectors (including phase-based scanners) can record the sun's direct or reflected rays as scan points. These points appear visually on a computer display as clouds within otherwise open areas of the scene.

Deflected beams: Mirrors and wet surfaces can deflect a scanner's beam to other surfaces. Spurious mirrored points are generally easy to spot on computer displays.

Edge/spot-size effects: When a laser beam hits the very edge of an object (e.g. steel beam), the recorded points can show up on a computer display as trailing away from the desired surface. Scanners with large beam diameters and phase-based scanners exaggerate these effects.

Ambiguity interval effects: Phase-based scanners, like GPS receivers, operate using ambiguity interval measurement techniques. A phase-based scanner with a "79m ambiguity interval" will record a surface that is 81m away as only 2m away (81m-79m = 2m). Such scan data is generally easy to spot on a computer display.

Other Related Sources

Scan filters: Some vendors use filters to reduce noise in scan data, remove sky noise, reduce edge effects (especially for phase-based scanners), or remove other types of spurious points. This can be a sore subject for surveyors, who generally prefer to gather raw data and decide for themselves if and how they want to apply filters.

Scanning modes: Scanners have evolved to have all sorts of "scanning modes." Examples are "low noise," "multiple-shots-per-point," "tilt sensing on/off," "evenly spaced shots on oblique surfaces," and more. Some modes can negatively affect accuracy and/or scan speed.

Instrument calibration and actual performance: Specs are just words and numbers on paper—a scanner's actual performance can be better or worse than its specs. For example, scanners can go out of calibration. As with other instruments, users should perform regular calibration checks and conduct independent QA checks for each survey.

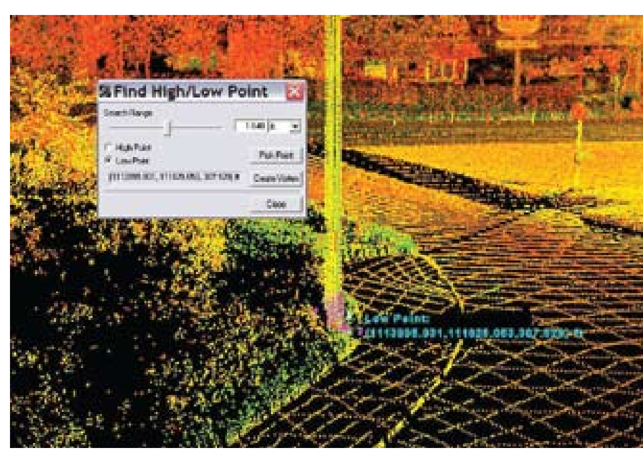
Geo-reference and registration errors: Coordinate errors can be introduced when scans are registered to each other and/or geo-referenced. For detailed insights, reference *Professional Surveyor Magazine*, July 2005, pp. 26-32.

Critical Role of Software

Okay, you've used the right scanner, scanning mode, and field procedures to help ensure your scan data meets the project's accuracy requirements. Now you're ready to select specific points for creating the map or other deliverables. How does one select from millions of scan points the individual points needed for the map and ensure that these are "the right points"? Here's where software comes into play.

Visualization and Navigation: Users often identify spurious points and locate optimal scan points by viewing the same scan data from varying perspectives. They also often display scan data with different colors, pixel size, shading, etc. These steps can chew up office time, so users prefer software that has the best visualization and navigation capabilities for fast manipulation of point clouds for optimal views, including automatic, simultaneous display of plan, profile and perspective views.

Automation: In many cases, users need to select ground points, lowest points, highest points, etc. to make the final map. If you're selecting points on a grid, how can you determine if the scan



▲ Office software can automatically locate and select lowest and highest points from clusters of high-definition survey data.

point nearest a grid line intersection is a scan point on the ground or a scan point on vegetation in that area?

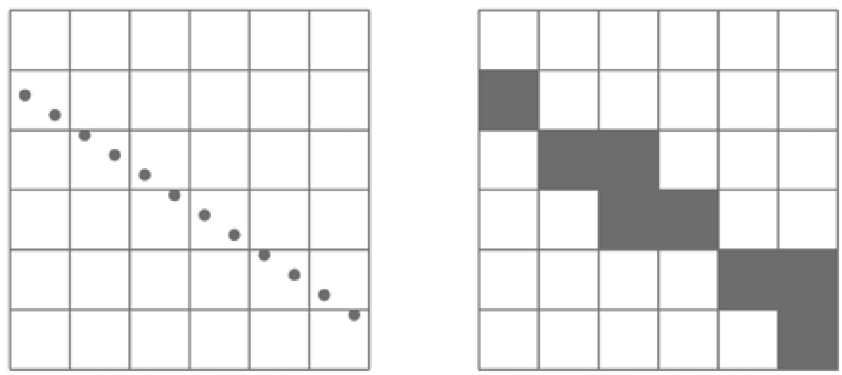
A major, recent breakthrough in office software for high-definition surveys is the automation of many parts of this "optimal point selection" process. Instead of manually rotating, panning, zooming and playing with colors, shading, etc. to try to select the best scan point, now algorithms quickly and rigorously search a selected group of points to identify the absolute highest or lowest coordinate among the set. This can be a significant time-saver and accuracy enhancer.

Vertical Exaggeration: this software tool is valuable for curb-gutter-road profiles, where it can otherwise be difficult to pick the most appropriate scan points. Vertical exaggeration artificially expands the profile view of the scan points, making it easy to select a true top-of-curb point, bottom-of curb point, and center-high-point on the road surface.

Display Options—Be Careful! Laser scan data can be displayed on a computer monitor in different ways, including direct display of points. All discussions above are based on using this approach. However, there are other point representation approaches that can be friendly to users, but users have to be very careful about the accuracy of their "point selection."

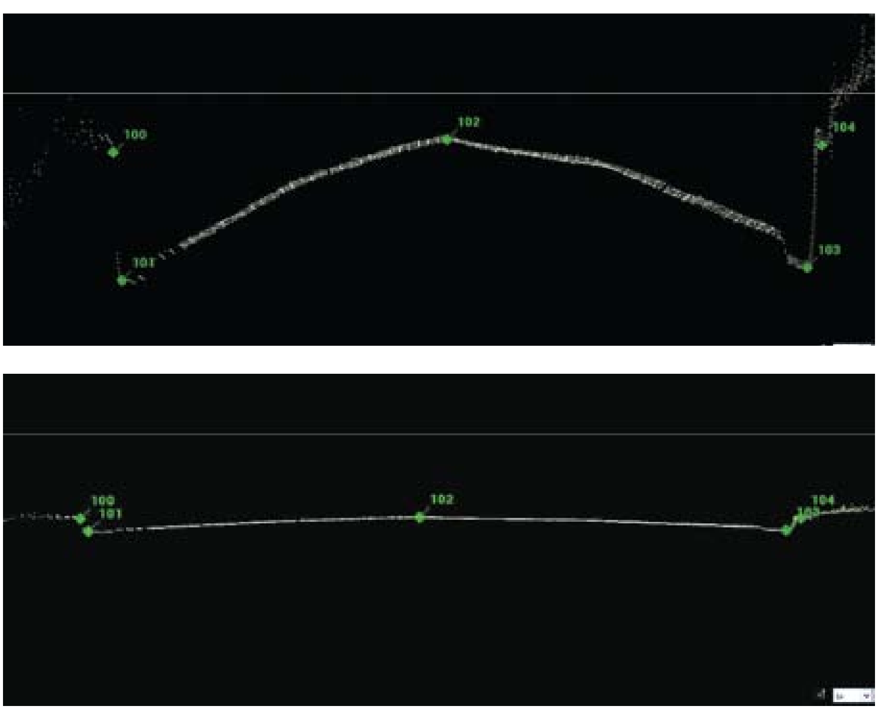
One friendly display option employs digital photos that are essentially draped over point clouds. Caveat: this is not photogrammetry! A user needs to be aware that (a) there is likely to be misalignment of the image to the underlying scan data which, even when significant, can be hard to detect, and (b) by picking a pixel from the image, the user is actually selecting the nearest scan point to that pixel. Depending on the density of the scan and other factors, this point may not accurately represent the optimal point selection.

Another "be careful" display option uses a spatial management technique called "voxels." A voxel is a small cubic volume of space. By subdividing a scanned area into 3D rows and columns of adjacent voxels, actual scan points will be "contained" within certain voxels. Advantages of converting point clouds into voxel representation are (a) scan file sizes can be reduced and (b) voxels display as smooth surfaces making them friendly to view. Their disadvantage is a sacrifice in accuracy. When users click on a voxel for a scan point coordinate, they get the coordinate of the center of the voxel; however, the actual scan point will be somewhere within the selected voxel's cubic space. Voxels tend to be large (generally much larger than the positional error of the scan point), so this representation can introduce significant error.



▲ Voxel representation (right) is created by marking each grid cube "filled" if a scan point lies inside it; this type of scan representation can introduce error.

Users of laser scan data routinely select specific scan points to use in creating deliverables. As such, it is important to understand the accuracy of specific scan points. Users can help ensure that selected points meet a project's accuracy requirements by (a) understanding a scanner's true accuracy and (b) using appropriate software tools and office procedures.



▲ Vertical exaggeration tool (see top image) in software helps users select best top-of-curb, bottom-of-curb, and high road surface points from scan data.

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