Understanding Spot Size

for Laser Scanning

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Several features of a laser scanner contribute to the level of definition it is capable of achieving in a high-definition survey. This article provides insight into spot size, as I have found that many professionals do not fully understand or appreciate the important subtleties of this feature.

As reported in an earlier article (Professional Surveyor Magazine, February 2005), several features of a scanner contribute to the level of definition or resolution that can be achieved via the data it collects. Since the greatest differentiating technical feature of a laser scanner, compared to traditional survey tools, is the detail it can collect, it helps to clearly understand these key contributing features:

- Scan density
- Scan noise
- Accuracy of each measurement
- Spot size

Generally, the higher the scan density, the less noisy the data, the higher the accuracy of each measurement, and the smaller the spot size, then the higher the definition of the survey.

Consider the two images in Figures 1 and Figures 2. These are scans from a rock face from two different models of scanners at a range of 25 meters from the scanner. Both scans represent the same scan density (i.e., vertical and horizontal spacing between scan points). The scan in Fig. 1 is higher definition than that in Fig. 2, as evidenced by the extra detail visible for the subject rock surface. The spot size of the scanner that captured the data in Fig. 1 was smaller than the spot size of the scan in Fig. 2. For scientists wanting to assess geologic formations, fractures, etc., this higher level of definition can offer significant value. (Note that spot size is also an important feature of a standard reflectorless total station, so some of the discussion in this article will also apply to better understanding and appreciating this feature for reflectorless total stations).

What is the Definition?

Today, it is rare for a laser scanner vendor to provide information in their specs about how they define their “spot size” or “beam diameter.” What exactly does a spot size of “6mm” or “15mm” or “50mm” mean? Is it the maximum diameter - fuzzy edge and all - or just the main, center part of the beam? How can you tell from a vendor’s spec?

There are currently two popular, yet different, definitions of spot size in industry. The first is based upon on a model of a Gaussian...
distribution of the beam’s intensity, or irradiance, across its diameter. Surveyors, engineers, physical scientists, and statisticians should all be generally familiar with the concept of Gaussian distribution as a type of statistical distribution with the familiar bell-shaped graphical representation. Basically, the Gaussian model of a laser beam characterizes the beam’s maximum intensity as being at the center of the beam, with intensity falling off in a Gaussian profile as you go outward (See Fig. 3). Many laser beams conform to this profile. The best laser beams, ones that give the minimum spot size over range, are always Gaussian in profile, what physicists call diffraction limited.

The second popular definition is the width of the beam at the half-intensity points. This is a more general definition that can be applied to any beam intensity profile, not just Gaussian profiles.

The second type of definition of beam diameter is the full-width half-height or FWHH-based definition. This definition asks the question, “At what diameter of the beam is the intensity of the beam equal to 50 percent of its maximum, center intensity, Imax?” Clearly, this definition results in a smaller beam diameter value than that based on the Gaussian diameter.

Either the Gaussian or FWHH definition is relevant as long as you compare apples to apples for different scanners. However, for those who like to pore over manufacturers’ specs, be careful. Unless a vendor is clear about how they define their spot size, there is no way to know if the spot sizes being compared are based on the same definition. There are currently no standards in the survey industry that cover this aspect, so vendors are free to define spot size however they like, using Gaussian diameter, FWHH diameter, or some other basis that they prefer. (Note that these kind of issues, such as how scan resolution relates to beam size, will be considered in the standards initiative on 3D Imaging Systems under the auspices of ASTM. Until such standards are in place, however, users are advised to do additional homework to properly understand vendor specifications).

Spot Size as a Function of Range

Another factor that complicates things for those doing their homework is the fact that a beam’s diameter varies as a function of its distance from the scanner. Unmodified, the diameter of a laser beam will naturally tend to increase with distance (see Fig. 4). So all other factors being equal, the definition of a scan will be less clear further away from the scanner (decreasing scan density as a function of increasing distance compounds this effect). The beam diameter from such scanners can easily grow to 10X or even more over the specified range of the scanner!
To calculate or estimate how large the beam will grow, vendors of these types of scanners usually specify the diameter of the beam at the exit of the scanner and then provide a divergence value. Typically stated in milliradians, or mrad, this reflects how fast the size of the beam grows as a function of distance. For example, a beam with a starting diameter of 10mm and a divergence value of 3 mrad will have a beam diameter of 160mm at a range of 50m from the scanner.

For scanners that use this approach - and many do - users may have to move the scanner around the site frequently to achieve the spot size and level of definition they want. Of course, each setup and tear-down takes time, so this has a direct impact on field productivity.

Collimated Beams

A second approach that some vendors use is to collimate the laser beam. The idea here is to insert a simple, non-moving beam expander (i.e. lens) that acts like a reverse telescope such that the beam stays relatively small over much of the scanner's useful range. In this case, a beam may exit the scanner at 6mm, for example, narrow down to 3 or 4mm at 25m range, and then increase back to 6mm at 50m range. Past 50m, the beam diameter will increase at a slightly higher rate than if the beam had not been collimated. The benefit is that the beam diameter will be <6mm from its exit point all the way out to 50m and it will still be smaller well beyond 50m than if the beam had not been collimated. With this approach, all surfaces in the <50m range are captured with a spot size <6mm. Users don't have to worry about spot size being too big within the 50m range. This type of approach can minimize the number of times the scanner has to be moved around the site to achieve the desired level of survey definition.

A third technical approach to optimizing spot size is to apply a variable beam expander in the path of the laser beam. The user can say, “From this, setup I want to achieve a spot size of Xmm at a distance of Ym” and then dials it in. On the surface, this approach may seem attractive, but it has potential drawbacks. To achieve a focused, small spot size further away, the beam will have to be larger closer to the scanner. So objects in the near-field will be captured with a bigger spot size, in some cases much larger depending on conditions. The same holds true for objects much further away. A second potential drawback is that variable beam expanders are moving, mechanical devices that can introduce additional error into each individual measurement and have to be calibrated over the full range of focus. So, while the visual definition of a particular object may appear better to the eye, the actual measurement accuracy may suffer. Another drawback is cost and reliability, as these approaches add cost and complexity to the optics system. Specifying the accuracy of such systems is also a challenge, as accuracy specs have to state the extent to which a beam is being focused for a particular measurement accuracy claim.

Try it Out

Regardless of how vendors specify their scanners with respect to spot size (or any other feature), some vendors are more conservative in their specs than others. So two scanners specified with the same spot size, and all other factors being equal, can still show differences in the level of definition achieved.

A scan beam that has a small diameter over a long, useful range can provide users with significant benefits in both the level of definition achieved and field productivity. Those evaluating laser scanning should be careful to understand the basis of vendors’ specs for this key feature and how a given scanner’s spot size changes with distance from any given scanner. Testing scanners and talking with peers who have used different types of scanners can also help in assessing this factor.

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