

# Dental Lab 3D Scanners

## – How they work and what works best

January 2012

Dr. Karl Hollenbeck, Dr. Thomas Allin, Dr. Mike van der Poel  
3Shape Technology Research, Copenhagen

Followers of the dental 3D scanner market are bombarded with a hail of different and confusing claims. Much too often, professionals seeking information are left hanging with difficult key questions such as “What is the difference between laser and white light scanners?” and “Can I compare the claimed accuracy between the different scanners?” This article is written to provide readers with a basic understanding of 3D scanning technology, thereby enabling them to better challenge 3D scanner manufactures and make a much more educated choice when purchasing a new scanner. This article primarily covers the scanning technology and only briefly touches on the aspects of the CAD software that is often included with the scanner.

### The basic principle of a 3D scanner

With one exception, all dental 3D scanners are constructed on the same basic principle. Fundamentally, a 3D scanner consists of a light source, one or more cameras, and a motion system supporting several axes for positioning the scanned object towards the light source and camera(s). The light source projects well-defined lines onto the surface of the object, and the camera(s) acquire images of the lines. Based on the known angle and distance between camera and light source (jointly called the scan head), the 3D position(s) where the projected light is reflected can be calculated using trigonometry. This measurement-principle is known as “triangulation.” The basic principle works with one camera only, but two cameras improve scan speed, accuracy and scan coverage.

Each line of projected light yields one 3D contour line. Therefore, the relative motion of the scan head and object yield multiple lines, and hence multiple 3D contours. Laser scanners generate multiple lines by moving the scan head along a precise linear axis (Figure 1, left), while white light scanners have a fixed scan head, but project several shifted line patterns from a central position consecutively (Figure 1, right). As can be seen from figure 1, the basic principles used in laser and white light scanners are the same. Hence, based on general scanner principle alone, it is impossible to claim that white light technology is better than laser technology or vice-versa.

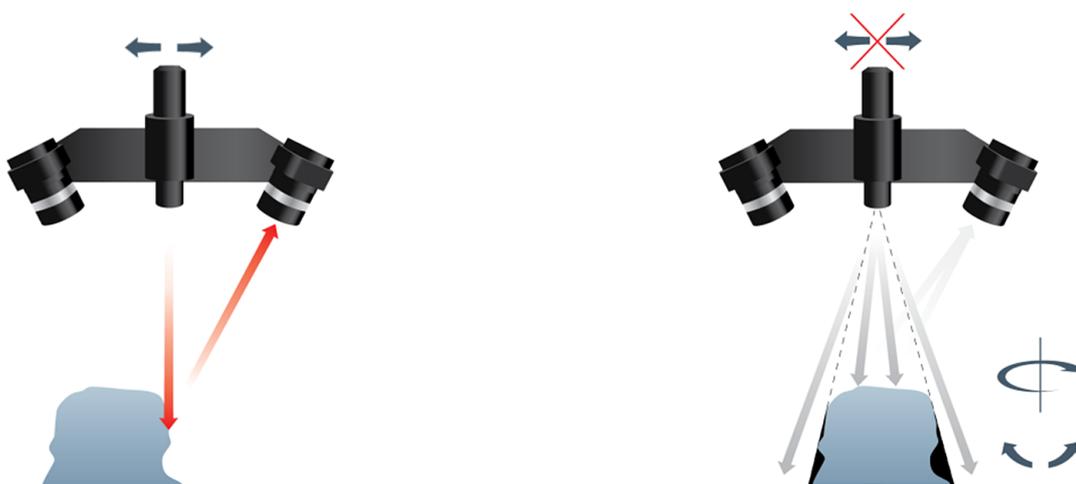


Figure 1: The 3D scanner principle. Left: A 3D laser scanner with two rotation axes and one linear axis. The laser scanner generates a line of light, which is moved across the object using the linear axes. Right: A white light scanner with two rotation axes. The light source generates multiple lines of light and thus an entire view from a single position.

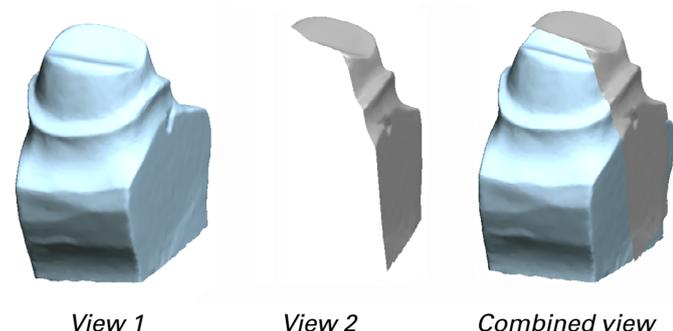
Each relative position of scan head and object, i.e., each set of contours, yields a single 3D view. All scanners run a predefined motion script moving the scan head relatively into several positions/views required to capture the surface from all sides (Figure 2). Some 3D scanners support a high-quality mechanical motion system, where all 3D views can be directly transformed into a common coordinate system and then simply appended to each other. Other 3D scanners, with less accurate mechanics do not rely on the motion system's quality but instead virtually align the 3D views by detecting similar 3D structures in overlapping regions of at least one pair of views. Software alignment thus works best for objects with pronounced structures, e.g. molars.

any illumination source (which is why they are perfect for use in pointers), but if not controlled carefully, they display speckle - a slight randomness in light intensity. In contrast, white-light scanners suffer from blur due to the fact that the different color components that exist in white light are refracted slightly differently (chromatic aberration, a "rainbow effect").

A 3D scanner's recording of sharply projected light patterns can be no better than the quality delivered by the cameras. High-quality in both optics and image sensors are therefore a must in 3D scanners for professional use. Today, the trend is turning towards developing scanners with high-resolution sensors – some up to 5 megapixels.

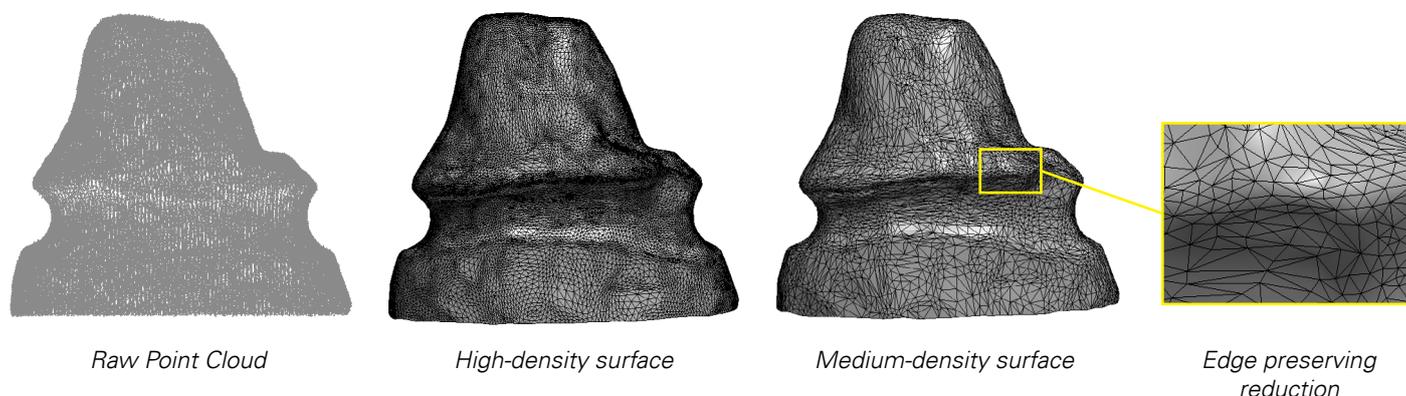
In the final processing step, the point cloud obtained from all views is converted into a 3D surface of fine triangles (Figure 3). This is an approximation method that is also used in computer graphics. Smart surface generation algorithms are preferable, i.e., those that preserve relevant features such as edges. Using smart algorithms the number of triangles can be significantly reduced without sacrificing accuracy. In general, reducing the number of triangles is desirable because the time it takes the CAD design software to process the 3D image is highly dependent on the number of triangles generated. For example, doubling the number of triangles could easily increase the software's processing time at least by a factor of four or in some cases, processing can even fail completely.

White light and laser 3D scanning technologies are also widely used in industrial applications and metrology. However, laser scanning systems dominate the segment for coordinate measurement machines and other high-accuracy applications.



**Figure 2:** In high-accuracy mechanical-motion-systems, the different views are appended. Less accurate systems apply software alignment of the different views. Software alignment relies on matches in the surface structure in overlapping areas. This makes software alignment prone to errors in areas that are small or display a smooth and less defined structure.

Triangulation requires sharply projected light patterns. These can in principle be obtained by both laser and white light scanners. Lasers can achieve minimal line widths of



**Figure 3:** Point cloud (left, 164,475 points) is used to generate the triangle based surface (middle; 55.380 triangles). Smart triangle reduction algorithms can be used to intelligently reduce the number of triangles (right; 13.845 triangles) while preserving excellent coping and margin line fit.

## Accuracy

Currently, there is no common standard for measuring and validating the accuracy of dental scanners. Most scanner manufacturers do not even disclose how they measure their accuracy claims. Hence, claimed accuracies – typically in the area of 20 microns - cannot be compared nor even confirmed.

The science of high accuracy measurement - metrology - applies reference objects with accuracies much higher than the scanner. These objects can only be manufactured by specialized accredited companies or metrology laboratories. By defining and introducing proper mutual reference objects such as these, it becomes clear that different scanner brands perform quite differently, and

many alarming results are revealed – for example, some scanners can round an edge incorrectly with an error margin of over 20 microns (Figure 4).

With implant bar reference objects, tests reveal an error of less than 3 microns along the insertion direction - i.e. in the level of the implants seating surface (Figure 5). This scanning error is the first in the CAD tolerance chain that in total, should reach less than a 10 micron vertical misfit between the framework and the abutments (the ideal “passive fit”). While it has been debated whether 10 microns is a realistically achievable value, there are at least some scanners that seem to be able to bring this ideal within reach.

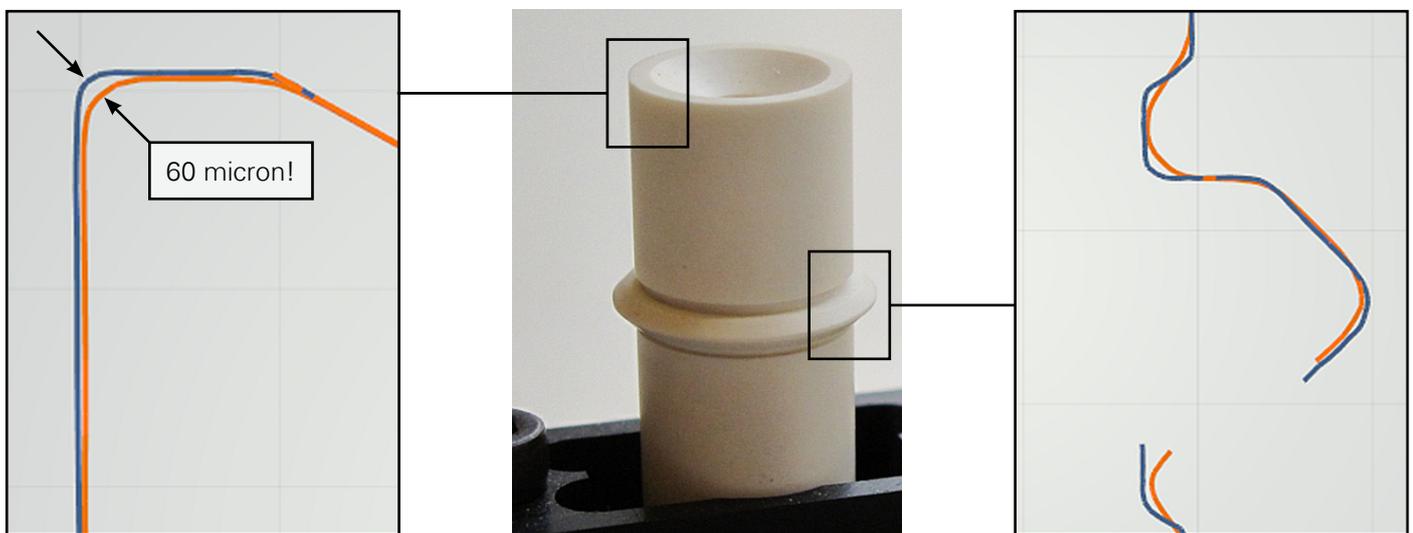


Figure 4: Two scanner brands' measurements (blue line, orange line) of a nominally sharp edge in a custom-made ceramic reference tooth object (middle). Note the relatively large difference in accuracy around the sharp edges.

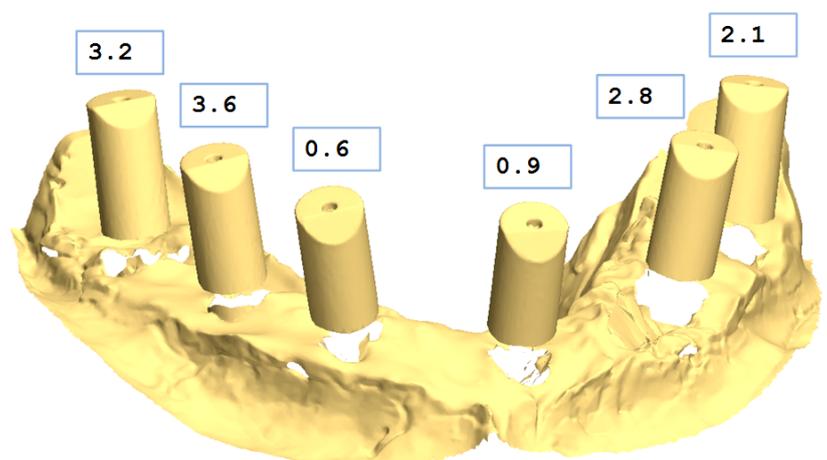


Figure 5: Left: Reference measurements with a high-end coordinate measurement machine (accuracy 3 microns). Right: Scan of an implant bar reference object with errors in the insertion direction [in microns].

It is an undeniable law of physics that all materials – and thus also scanner hardware – will expand and contract according to changes in temperature. Scanner hardware can also be affected by rough handling such as during transportation. For demanding work, such as long span bridges and implant bars, it is especially important that a scanner is re-calibrated when moved or when the lab's temperature changes. State-of-the-art scanners come with special calibration objects with a known accuracy factor that is much higher than the scanner's accuracy capability. Software algorithms cannot compensate for temperature effects because the scanner hardware itself contains weldings, fasteners, glued sections, varying loads, etc., and is thus prone to highly complex expansion and contraction.

Accuracy also depends on how well the scanner is manufactured. Larger 3D scanner manufacturers typically have better production facilities and tools, and can automate parts of the assembly steps including outgoing quality inspection. They can thereby reduce product variability to lower levels than those achievable through human manufacturing operations alone. Larger manufacturers are also usually financially stable and are thus most likely to remain in business and provide long-term support.

## Scan Speed and productivity

Scan speed is an important parameter when choosing a scanner, because scan time is an essential factor in the overall productivity. As with accuracy, there are no standards that make it easier to compare marketing material and claims. While there is no common reference, empirical comparisons show that claimed scan times can vary from 30 seconds to several minutes for the same basic die. The more serious manufacturers will disclose their scan times for selected major indications. Generally speaking, studying scan time values alone will not reveal

the scanner's capabilities in terms of productivity. Labs need to consider whole workflows, starting with order creation and ending with a 3D scan that is fully ready for CAD design. This naturally involves the scanner hardware but also the system that drives it. Comparing different scanner brand's productivity from this angle will reveal even larger performance variations.

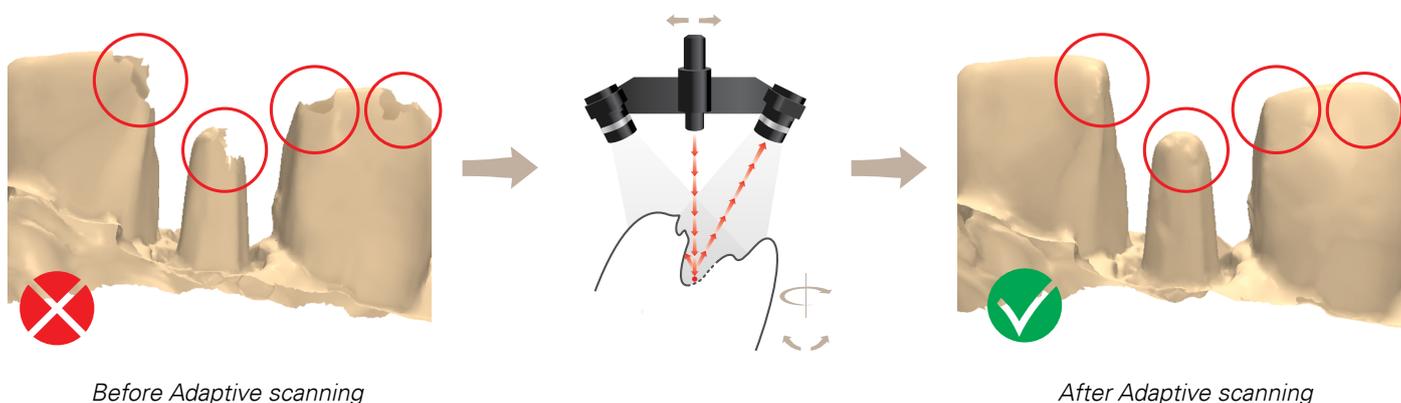
A high degree of automation will allow the user to spend less time on the overall scan process. Automation also reduces the likelihood of human errors and thus helps avoid remakes - the most time-consuming of all errors. For example, manually controlled camera brightness-adjustment can result in over-exposed images in which projected lines of light can no longer be detected.

Some hardware features can save handling time. With a die feeder or multi-die plate, a scanner can work without an operator for many minutes. A single technician can work with multiple scanners simultaneously or efficiently use the spare time for designing restorations in the CAD software. Good fixtures reduce the number of failures, an annoying source of wasted time.

The most truthful sources of information for scan speed are probably found in impartial user statements (especially regarding failure rates) and in videos that show entire scan processes.

## Additional functionality

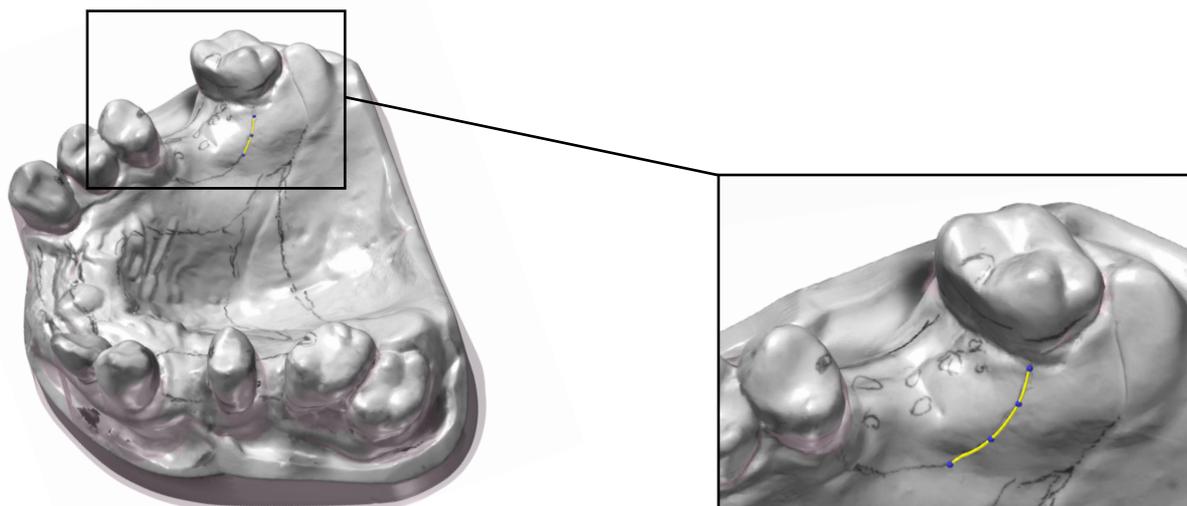
Besides accuracy and scan speed, there are several other important differences between dental scanners. A major factor labs should consider is the number of indications that the scanner supports, e.g. long span bridges, Customized Abutments, accurate Implant Bars and Removable Partial Dentures. Too many low-end non-upgradable scanners will only support the very basic indications and thus limit the lab and represent a weak investment long-term.



**Figure 6:** Left: Example of a traditional impression scan result that is incomplete in the preparation proximal and contact areas, and will thus jeopardize fit and clinical performance. Right: A complete and accurate scan after "Adaptive Impression Scanning" of incomplete areas by automatically applying the optimal combination of two cameras and three-axis motion.

The scanner's supported indications cannot be viewed on their own. The CAD software running with the scanner will need to support them as well. In general, manufacturers that develop both scanners and CAD software will typically offer better and optimized workflows with fully integrated solutions - especially in terms of indication support and user-friendliness.

Looking forward, impression scanning is expected to become the most widely used method for 3D scanning in the lab, leaving conventional "gypsum only" scanners obsolete. Impression scanning is particularly challenging for a 3D scanner. The deep cavities make it difficult for the camera and light source to both illuminate and see deep surface points simultaneously, a basic requirement for the reconstruction of the 3D model (Figure 6). Multiple cameras increase the chance of being able to see the entire surface. There is a proprietary technology ("adaptive impression scanning") that applies software to find the optimal combination of cameras and positions to re-scan uncovered areas. Other manufacturers use time-consuming and heavy pre-defined motion scripts.



*Figure 7: Texture Scanning captures 2D images of the model surface and precisely overlays these on the 3D model.*

Unlike adaptive scanning, pre-defined motion scripts do not at all guarantee complete coverage of the surface.

Based on high-resolution (5 MP) camera technology, Texture Scanning captures 2D images of the gypsum model surface and precisely overlays these on the 3D model, thereby enhancing visualization of surface details and allowing technicians to include hand-drawn design guidance markings in the digital design (Figure 7). This is particularly useful for capturing a hand-drawn margin line penciled directly on the physical model or for transferring RPD framework position markings from the model into the CAD software. Texture scanning is a new groundbreaking technology that is supported in only the most advanced dental scanners.

Dental scanners come with a built-in PC. Although this reduces space requirements and eases transportation, it presents a significant investment drawback.

Scanner PCs typically need to be upgraded every 2-3 years due to continuously increasing demands on operating systems and CAD software – and built-in PCs are often difficult to upgrade.

## Summary

Due to the lack of common standards for even the most basic features in dental lab scanners, the 3D scanner market can be confusing for many labs on the lookout for the right device. Labs should consider the following check list when comparing dental 3D scanners:

- Accuracy – documented by certified reference objects
- Scan and workflow time – for well defined indications
- Range of supported indications – long span bridges, implant bars, removable bars
- Useful features – impression scanning, texture scanning, die feeder, calibration object and 5 MP cameras.

Finally, it is highly recommended to always test the scanner before making a final purchase. The advertisement and brochure may have made all sorts of promises but these may not always be fulfilled when getting down to real work.

With such an important and long-term investment for the lab, it is only natural to thoroughly investigate the markets and challenge poorly documented manufacturer claims.