# 3D scanning and scan processing

by Michael Raphael

The field of 3D scanning continues to grow in significance. One primary reason has been the intense growth in the use of 3D printing and other digital fabrication methods, especially in the industrial AM market. Quite often, physical objects, spaces, and even people are 3D scanned and then digitally modeled (i.e., *reverse engineered*). This is done for documentation purposes, or so they can be 3D printed, analyzed, or dimensionally inspected. Scan data is also being produced for use in augmented reality (AR) and virtual reality (VR) applications. Various tools and methods for capturing the 3D shape and sometimes color of real-world parts, tools, spaces, artifacts, or even a human body have become quite common.

The awareness and demand for 3D scanning continues to increase for many reasons. The variety of 3D capture hardware is continually expanding and often dropping in price. New software products for converting raw 3D data into usable digital formats, such as CAD models, are being developed and deployed faster than ever. With the increased interest and broadened offerings in 3D scanning, a growing number of developers, manufacturers, and resellers are focused on the field. A fair amount of consolidation has also occurred in the recent past. Appendix D provides a list of 3D scanning hardware products. 3D scan-processing software products are provided in Part 4: Final Part Production.

## 3D scanning's past

For over 30 years, the applications for 3D scanning have steadily widened beyond its early use for dimensional metrology in the aerospace, automotive, and power generation industries. The measurement instruments used for these industrial metrology applications are still relatively complex and remain expensive. Today, much less expensive 3D scanning equipment is being used, and the technology can be found in many educational institutions and some homes. Even a simple digital camera in mobile devices can be used as a 3D scanner for many interesting applications. Nevertheless, industrial customers have always been, and still are, the primary funding source for 3D scanning technology R&D.

Low-cost digital camera used for 3D scanning a marble bust (left), and the scan data and conversion to a 3D model (right), courtesy of Direct Dimensions, Inc.

Modern industrial coordinate metrology started in the 1940s with the proliferation of fixed coordinate measurement machines (CMMs) and optical measurement devices. Companies used these metrology devices to check large tools and fixtures used to fabricate critical parts in the aerospace, automotive, and other manufacturing industries. In the 1980s, computers and CAD software began to take hold in product design processes. Manufacturing and quality engineers looked to improve methods of dimensional inspection of large parts and assemblies, especially for critical aerospace parts. Measurement instruments, such as optical theodolites and film-based photogrammetry devices, were dramatically improved by the development of computers, digital electronics, and coherent lasers.

Portable metrology equipment emerged that allowed 3D measurement to take place on the factory floor instead of inside a dedicated CMM room. New instruments such as laser and optical trackers, portable arm CMMs, and structured-light scanners became available. They helped engineers solve critical manufacturing issues, which led to increased demand and more R&D by scanner manufacturers. Using these tools, parts designed and engineered in 3D CAD could be inspected directly, sometimes while still on a machine or in a tooling fixture. Thus, 3D scanning technologies have experienced dramatic improvements in speed, accuracy, portability, and reliability at a rate similar to that of the electronics industry.

Two examples of portable articulated arm CMMs being used for 3D measurement in a manufacturing environment, courtesy of Direct Dimensions, Inc.

## Current state of 3D measurement

Different classes of equipment are available for 3D measurement, including various styles of non-contact scanners and contact probe-based digitizers. Fixed CMMs, often with heavy granite bases for stability, are still prevalent in many industrial machine shops and large automotive assembly plants. Portable articulating arms, laser trackers, and optical trackers provide similar probe-based metrology capabilities with the benefit of range and portability. Many such portable CMM systems can now be fitted with laser line scanners. This adds non-contact scanning capabilities as well as touch probe discrete measurement.

Structured light technology offers high scan density and near instantaneous capture over a small area, usually less than 1 x 1 m (39 x 39 inches). The area can be, and often is, reduced with lenses to proportionally increase both resolution and accuracy. Line-of-sight is always required, as well as a way to align the scan patches with targets or previous passes. These systems are often paired with a motorized turntable or a more sophisticated motion platform, such as an industrial robot, for automated 3D scanning and data alignment. Automation of such inspection systems is becoming increasingly prevalent with the growth in robotics and control systems.

For objects with internal geometric features, industrial CT imaging has become a very effective means of data acquisition. With recent commercial development, sophisticated industrial CT systems are widely available from several large OEMs and service providers. Depending on the class of system, the technology has limitations, primarily in terms of maximum scan size and range of materials. However, improvements in speed and resolution have made the inspection of relatively complex parts and assemblies quite feasible.

For scanning larger objects, such as aircraft, ships, wind turbines, buildings, and construction sites, a fast-growing category of scanning technology has emerged. Known as spherical scanners, these instruments have transformed the traditional surveying industry. Many surveyors and engineers are rapidly adopting these tripod-mounted, area-scanning instruments. Their benefits include relative ease of use, improved scanning accuracy and density, and speed advantages, compared to conventional line-of-sight optical instruments. They are generally considered “long range” scanners with capabilities in the range of hundreds of meters. They provide the capability to quickly set up and capture entire factories, crime scenes, movie sets, and many other large-scale targets. They are often capable of capturing color as well as geometric data.

Large-scale scanning applications include airplanes, art, architecture, and artifacts, courtesy of Direct Dimensions, Inc.

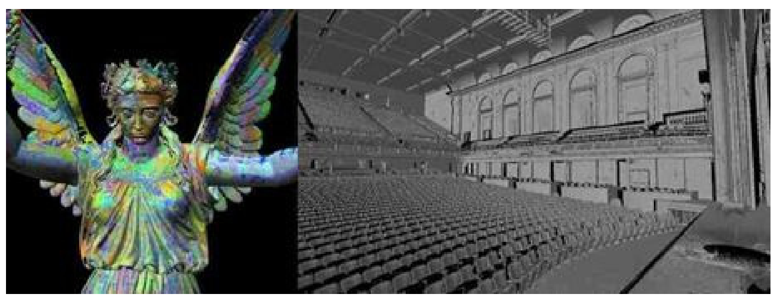
## Post-processing 3D data

3D scanning systems typically capture large quantities of 3D coordinate values known as point clouds. Depending on the scanner and the nature of the project, the result of scanning is often a large number of point cloud data files, with each file being extremely large. The size of point cloud files from 3D scanners has grown almost exponentially every year. Transforming these point clouds into effective formats for downstream use can be challenging and time-consuming. Many projects require highly specialized software, intensive computing power, and operator skill that can take years to develop.

Scanning tools, such as CMM arms and laser trackers that use a contact touch probe, capture significantly less data than laser, structured-light, and CT scanning methods. The 3D data points from these 3D digitizing tools are often transformed into geometric features by onboard software in real time. Frequently, this software function is integrated directly with the physical measurement operation. Several software products have been developed that allow nearly every brand and type of 3D measurement instruments to interface with one another in a single platform. This provides a common environment and allows large enterprises to have a single software product for multiple operators to learn and use.

Most of the "heavy lifting" for transforming dense point clouds is handled by a specific class of post-processing software. These tools bridge the gap between the raw scan data and the downstream end use, which is typically in 3D CAD software. They have become integral in the use of scanners for both reverse engineering and dimensional inspection applications.

Another growing market for point cloud processing is the use of conversion tools for very large terrestrial, mobile, and aerial files. Several solutions have entered this market, especially for architectural and infrastructure modeling, facilities and plants, and GIS mapping. Early demand for these solutions came from the oil and gas industry and from the architectural, engineering, and construction industry. These solutions enable as-built documentation of existing facilities for the purpose of retrofit design and analysis.



Most scanners capture dense data requiring sophisticated post-processing software, as shown in these scans of a sculpture and the interior of the Lyric Theatre, courtesy of Direct Dimensions, Inc.

## Consumer 3D scanning

A new set of 3D scanning tools has emerged that is democratizing cost and availability for individual consumers. Mobile phone-based photography apps bring the concept of capturing objects and scenes to the masses. This is similar to the way low-cost desktop 3D printers are democratizing 3D printing. Many of these solutions are even free, but they produce varying scan quality. Other low-cost tools have launched recently, some through crowdfunding platforms. These new 3D scanning tools include several solutions that capture a rotating object with a projected laser line. By projecting a structured light source onto surfaces, this movement-based 3D imaging can be more accurate than using still digital camera images. However, the technology is usually more expensive.

Typical 3D-printed figurines made by various types of 3D scanning systems, courtesy of Direct Dimensions and ShapeShot

## What's next?

Industrial and professional applications remain the most demanding and command the bulk of the overall 3D scanning market. However, the consumer and "prosumer" segments are quickly gaining attention because of their potential. Business models are continuing to develop that leverage product customization through AM and consumer 3D printing. Many of these new models are focused on customizing the fit of products to the human body. Examples of mass-market-aimed personalized products enabled by 3D scanning include shoe orthotics and footwear, earbuds for earphones, and clothing.

These concepts are following the patterns of the well-established and compelling successes in medical and dental areas, such as hearing aid shells and dental implants. The use of 3D scanning and 3D printing in combination to make personalized products is a business model that is almost certain to grow. Such end-to-end solutions that can be automated and tied to e-commerce models could gain widespread adoption, provided the content is useful and interesting.

In the meantime, 3D scanners continue to enter our daily lives in dental and medical offices as well as some shoe and clothing stores. We will also see them at accident scenes, construction projects, classrooms, libraries, social events, and in courtrooms. Scanners are showing up in maker and hacker spaces, art events, exercise gyms, shopping malls, and even social events in the form of 3D photo booths. Several startups have launched full-body scanning booths for body measurement for apparel as well as to make color, full-body 3D figurines. Market-defining "killer apps" that combine both 3D scanning and 3D printing have yet to emerge. However, given the personalization that these technologies allow, human body-centric businesses are likely to be successful.