3D scanning and scan processing

by Michael Raphael

The field of 3D scanning continues to grow in significance. In fact by many accounts, it may be starting to rival 3D printing in terms of its level of interest. Clearly one primary reason has been the intense growth in the use of 3D printing, especially in the consumer market. Quite often physical objects, spaces, and especially people are being 3D scanned and digitally modeled so that they can be 3D printed. Various tools and methods for capturing the shape of real-world parts, tools, sculptures, or even a human body in three dimensions for various downstream uses, including 3D printing, has become quite common.

The awareness and use of 3D scanning continues to increase for many reasons. The variety of different 3D capture hardware is continually expanding. 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 H provides a list of 3D-scanning hardware products, and Appendix I lists 3D-scanning software products.

Primary uses

Over the past quarter century, 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 expensive. Today, much less expensive equipment is being employed for 3D scanning, and the technology has found its way into many educational institutions and some homes. Even a simple digital camera in mobile devices today 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 resultant scan 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 in the fabrication of critical parts in the aerospace, automotive, and other manufacturing industries. In the 1980s, computers and CAD software began to take hold in industrial design processes. Manufacturing and quality engineers looked to improve methods of dimensional inspection of large parts and assemblies, especially for critical aerospace parts. The early 1980s measurement instruments, such as optical theodolites and film-based photogrammetry devices, were dramatically improved by the development of computers, digital electronics, and coherent lasers.

A new class of 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 helped engineers solve critical manufacturing issues, which led to increased demand and more R&D by scanner manufacturers. Parts were designed and engineered in 3D CAD and could be inspected directly, sometimes while still on a machine or in a tooling fixture, using these advanced 3D measurement and analysis tools. Thus, 3D-scanning technologies have experienced dramatic improvement in speed, accuracy, portability, and reliability at a rate that is similar to growth in 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 digitizers. Fixed CMMs, often with heavy granite bases for stability, are still prevalent in many industrial machine shops. Portable articulating arms, laser trackers, and optical trackers provide similar probe-based metrology capabilities with the benefit of range and portability. Most portable CMM systems, such as arms, laser trackers, and optical trackers, 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 the benefit of high scan density and near instantaneous capture, since coverage is over a small area (usually less than one meter by one meter). The area can be, and often is, reduced with lenses to increase both resolution and accuracy significantly. Line of sight is always required, as well as a way to align the scan patches with targets or scan overlap. 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.

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 a number of 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, and buildings and sites, a fast-growing category of scanning technology known as spherical scanners has transformed the traditional surveying industry. Many surveyors and engineers are rapidly adopting these tripod-mounted area-scanning instruments because of their relative ease of use, scanning accuracy and density, and speed advantages as compared to conventional single-point line-of-sight optical instruments. Generally considered “long-range” scanners with capabilities in the hundreds of meter range, they provide the capability to quickly set up and capture entire factories, crime scenes, movie sets, and many other larger scale targets, including color information.

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

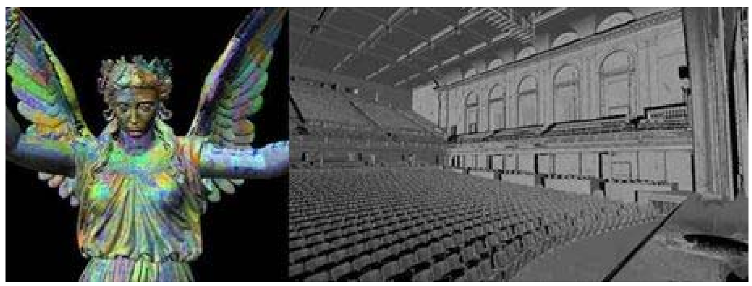
Post-processing 3D data

3D-scanning systems capture large quantities of 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 files, with each file being extremely large. Point clouds from 3D scanners have grown at an almost exponential rate every year. Transforming these point cloud files into effective formats for downstream use can be the most challenging and time-consuming aspects of a project. Many projects require highly specialized software, intensive computing power, and operator skills 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. 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. Some software products have been developed that allow almost all brands and types of 3D measurement instruments to interface with one another together in one platform. This provides a common environment and allows large enterprises to have a single software product for multiple operators to learn and use.

Whether the 3D measurement data is processed in enterprise software or from a hardware manufacturer's data capture product, most of the "heavy lifting" for transforming dense point clouds is handled by a specific class of post-processing software. Special point cloud-processing software tools have been developed to bridge the gap between the raw scan data and the downstream end use, which is typically in CAD software. These products have become integral for 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. A number of solutions have entered this market, especially for architectural and infrastructure modeling, facilities and plants, and GIS mapping. Much of the demand for these solutions is coming from the oil and gas industry and from the architectural/engineering/construction industry for as-built documentation of existing facilities for the purpose of retrofit design.



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 apps, such as 123D Catch from Autodesk and the RealSense sensor from Intel, 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, although one often gets what one pays for: the free applications do not always deliver the best results. Other low-cost tools have launched recently, some through crowd-funding 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 active-based 3D imaging can be more accurate than using still digital camera images, although 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?

While industrial and professional applications remain the most demanding and command the bulk of the overall 3D scanning market, the consumer and "prosumer" segments are quickly gaining attention because of their sheer potential. Business models are developing 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. Current examples of mass market-aimed startups that are enabled by 3D scanning include personalized shoe orthotics and footwear, ear buds for earphones, and even personalized apparel. 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 products that are custom and personalized is a business model that is almost certain to grow. Such end-to-end solutions that can be automated, mechanized, and tied to e-commerce models could gain traction and widespread adoption, especially if the content is useful and interesting.

In the meantime, 3D scanners will continue to enter our daily lives in dental and medical offices, and also at accident scenes and courtrooms, construction projects, classrooms, and social events. Scanners are showing up in hacker spaces, art events, exercise gyms, shopping malls, and 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 full-color, full-body 3D figurines. Market-defining "killer apps" for 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.