

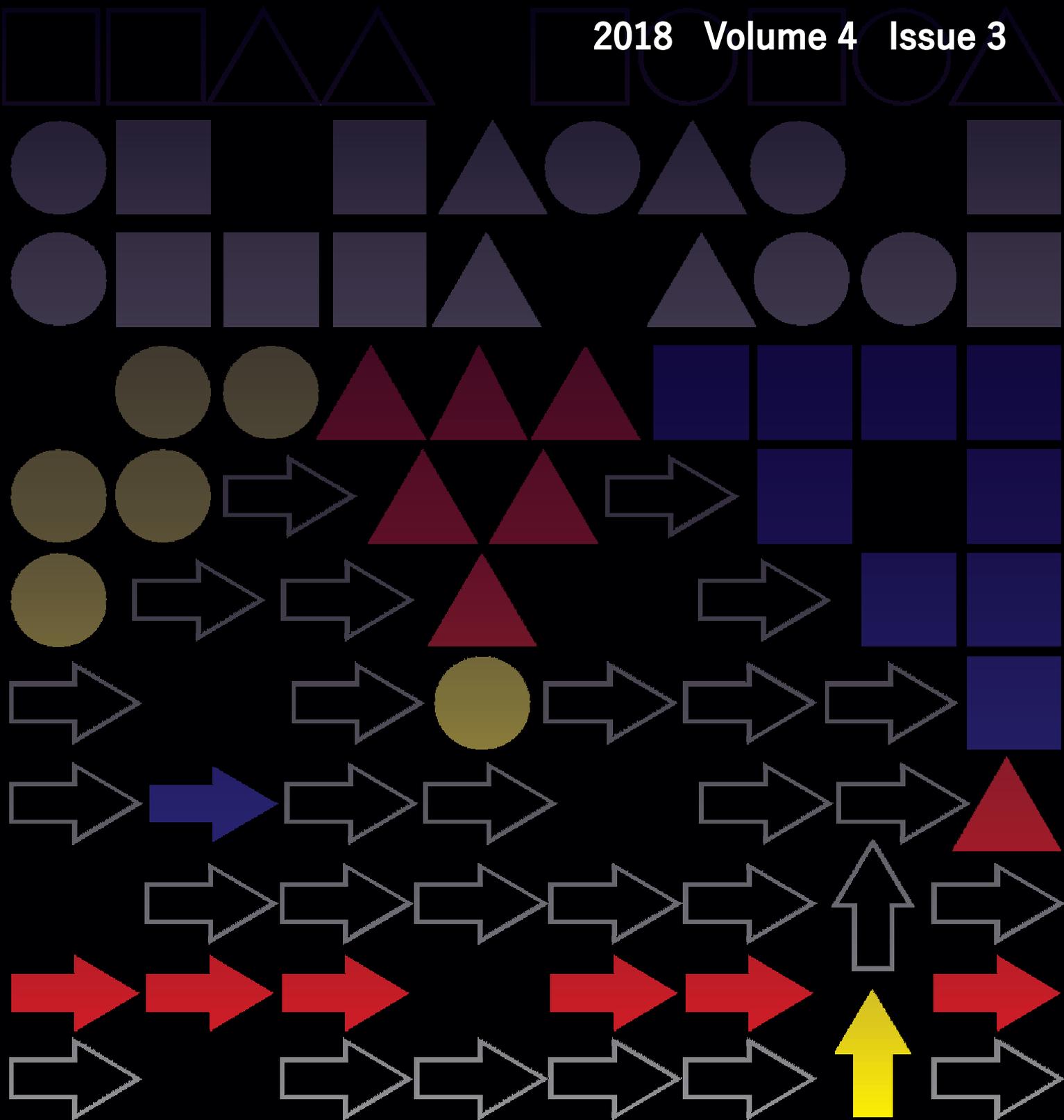
ACTA SIMULATIO

International Scientific Journal about Simulation

electronic journal
ISSN 1339-9640



2018 Volume 4 Issue 3





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(SEPTEMBER 2018)

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3D SCANING – TECHNOLOGY AND RECONSTRUCTION

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3D SCANING – TECHNOLOGY AND RECONSTRUCTION

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Keywords: technology, reconstruction, 3D scanning, 3D scanner, light, point cloud

Abstract: 3D Laser Scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light. 3D laser scanners create “point clouds” of data from the surface of an object. In other words, 3D laser scanning is a way to capture a physical object’s exact size and shape into the computer world as a digital 3-dimensional representation. There are many of technologies that we can get the required digitization of objects, buildings or natural scenery. It is just few examples what we can do to scan.

1 Introduction

A 3D scanner can be based on many different technologies, each with its own limitations, advantages and costs. Many limitations in the kind of objects that can be digitised are still present, for example, optical technology, may encounter many difficulties with shiny, mirroring or transparent objects. For example, industrial computed tomography scanning and structured-light 3D scanners can be used to construct digital 3D models, without destructive testing.

Collected 3D data is useful for a wide variety of applications. These devices are used extensively by the entertainment industry in the production of movies and video games, including virtual reality. Other common applications of this technology include augmented reality, motion capture, gesture recognition, industrial design, orthotics and prosthetics, reverse engineering and prototyping, quality control/inspection and the digitization of cultural artifacts.

2 Functionality

The purpose of a 3D scanner is usually to create a 3D model. This 3D model consists of a point cloud of geometric samples on the surface of the subject. These points can then be used to extrapolate the shape of the subject (a process called reconstruction). If colour information is collected at each point, then the colours on the surface of the subject can also be determined [1].

3D scanners share several traits with cameras. Like most cameras, they have a cone-like field of view, and like cameras, they can only collect information about surfaces that are not obscured. While a camera collects colour information about surfaces within its field of view, a 3D scanner collects distance information about surfaces within its field of view. The “picture” produced by a 3D scanner

describes the distance to a surface at each point in the picture. This allows the three dimensional position of each point in the picture to be identified.

For most situations, a single scan will not produce a complete model of the subject. Multiple scans, even hundreds, from many different directions are usually required to obtain information about all sides of the subject. These scans have to be brought into a common reference system, a process that is usually called alignment or registration, and then merged to create a complete 3D model. This whole process, going from the single range map to the whole model, is usually known as the 3D scanning pipeline.

3 Technology

There are a variety of technologies for digitally acquiring the shape of a 3D object. A well established classification divides them into two types: contact and non-contact. Non-contact solutions can be further divided into two main categories, active and passive. There are a variety of technologies that fall under each of these categories.

3.1 Contact

Contact 3D scanners probe the subject through physical touch, while the object is in contact with or resting on a precision flat surface plate, ground and polished to a specific maximum of surface roughness. Where the object to be scanned is not flat or can not rest stably on a flat surface, it is supported and held firmly in place by a fixture.

The scanner mechanism may have three different forms:

- A carriage system with rigid arms held tightly in perpendicular relationship and each axis gliding along a track. Such systems work best with flat profile shapes or simple convex curved surfaces.

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- An articulated arm with rigid bones and high precision angular sensors. The location of the end of the arm involves complex math calculating the wrist rotation angle and hinge angle of each joint. This is ideal for probing into crevasses and interior spaces with a small mouth opening.

- A combination of both methods may be used, such as an articulated arm suspended from a traveling carriage, for mapping large objects with interior cavities or overlapping surfaces.

3.1.1 CMM

A CMM (coordinate measuring machine) is an example of a contact 3D scanner (Figure 1). It is used mostly in manufacturing and can be very precise. The disadvantage of CMMs though, is that it requires contact with the object being scanned. Thus, the act of scanning the object might modify or damage it. This fact is very significant when scanning delicate or valuable objects such as historical artifacts. The other disadvantage of CMMs is that they are relatively slow compared to the other scanning methods. Physically moving the arm that the probe is mounted on can be very slow and the fastest CMMs can only operate on a few hundred hertz. In contrast, an optical system like a laser scanner can operate from 10 to 500 kHz.

Other examples are the hand driven touch probes used to digitise clay models in computer animation industry.



Figure 1 A coordinate measuring machine with rigid perpendicular arms [2]

3.2 Non-contact active

Active scanners emit some kind of radiation or light and detect its reflection or radiation passing through object in order to probe an object or environment. Possible types of emissions used include light, ultrasound or x-ray.

3.2.1 Time-of-flight

The time-of-flight 3D laser scanner is an active scanner that uses laser light to probe the subject. At the heart of this type of scanner is a time-of-flight laser range finder. The

laser range finder finds the distance of a surface by timing the round-trip time of a pulse of light. A laser is used to emit a pulse of light and the amount of time before the reflected light is seen by a detector is measured. Since the speed of light c is known, the round-trip time determines the travel distance of the light, which is twice the distance between the scanner and the surface. If t is the round-trip time, then distance is equal to $c.t/2$. The accuracy of a time-of-flight 3D laser scanner depends on how precisely we can measure the t time: 3.3 picoseconds (approx.) is the time taken for light to travel 1 millimetre.

The laser range finder only detects the distance of one point in its direction of view. Thus, the scanner scans its entire field of view one point at a time by changing the range finder's direction of view to scan different points. The view direction of the laser range finder can be changed either by rotating the range finder itself, or by using a system of rotating mirrors. The latter method is commonly used because mirrors are much lighter and can thus be rotated much faster and with greater accuracy. Typical time-of-flight 3D laser scanners can measure the distance of 10,000~100,000 points every second.

Time-of-flight devices are also available in a 2D configuration. This is referred to as a time-of-flight camera as we can see on figure 2.



Figure 2 Lidar scanner for scanning buildings rock formations, etc. [2]

3.2.2 Triangulation

Triangulation based 3D laser scanners are also active scanners that use laser light to probe the environment. With respect to time-of-flight 3D laser scanner the triangulation laser shines a laser on the subject and exploits a camera to look for the location of the laser dot. Depending on how far away the laser strikes a surface, the laser dot appears at different places in the camera's field of view. This

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technique is called triangulation because the laser dot, the camera and the laser emitter form a triangle. The length of one side of the triangle, the distance between the camera and the laser emitter is known. The angle of the laser emitter corner is also known. The angle of the camera corner can be determined by looking at the location of the laser dot in the camera's field of view. These three pieces of information fully determine the shape and size of the triangle and give the location of the laser dot corner of the triangle (Figure 3). In most cases a laser stripe, instead of a single laser dot, is swept across the object to speed up the acquisition process. The National Research Council of Canada was among the first institutes to develop the triangulation based laser scanning technology in 1978.

3.2.3 Strengths and weakness

Time-of-flight and triangulation range finders each have strengths and weaknesses that make them suitable for different situations. The advantage of time-of-flight range finders is that they are capable of operating over very long distances, on the order of kilometres. These scanners are thus suitable for scanning large structures like buildings or geographic features. The disadvantage of time-of-flight range finders is their accuracy. Due to the high speed of light, timing the round-trip time is difficult and the accuracy of the distance measurement is relatively low, on the order of millimetres.

Triangulation range finders are exactly the opposite. They have a limited range of some meters, but their accuracy is relatively high. The accuracy of triangulation range finders is on the order of tens of micrometres.

Time-of-flight scanners' accuracy can be lost when the laser hits the edge of an object because the information that is sent back to the scanner is from two different locations for one laser pulse. The coordinate relative to the scanner's position for a point that has hit the edge of an object will be calculated based on an average and therefore will put the point in the wrong place. When using a high resolution scan on an object the chances of the beam hitting an edge are increased and the resulting data will show noise just behind the edges of the object. Scanners with a smaller beam width will help to solve this problem but will be limited by range, as the beam width will increase over distance. Software can also help by determining that the first object to be hit by the laser beam should cancel out the second.

At a rate of 10,000 sample points per second, low resolution scans can take less than a second, but high resolution scans, requiring millions of samples, can take minutes for some time-of-flight scanners. The problem this creates is distortion from motion. Since each point is sampled at a different time, any motion in the subject or the scanner will distort the collected data. Thus, it is usually necessary to mount both the subject and the scanner on stable platforms and minimise vibration. Using these scanners to scan objects in motion is very difficult.

Recently, there has been research on compensating for distortion from small amounts of vibration and distortions due to motion and/or rotation.

When scanning in one position for any length of time slight movement can occur in the scanner position due to changes in temperature. If the scanner is set on a tripod and there is strong sunlight on one side of the scanner then that side of the tripod will expand and slowly distort the scan data from one side to another. Some laser scanners have level compensators built into them to counteract any movement of the scanner during the scan process.

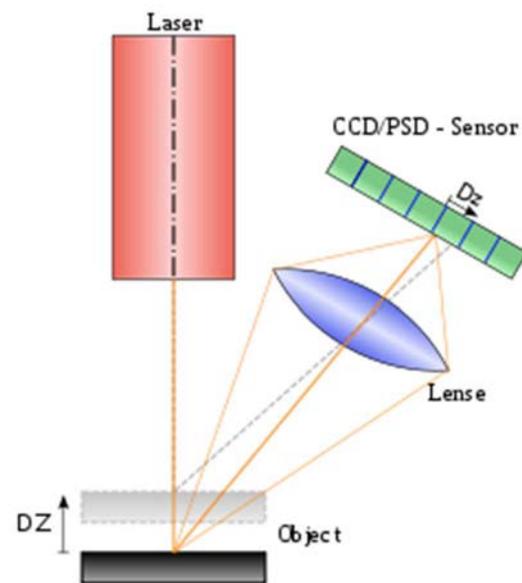


Figure 3 Principle of triangulation sensor. Two object positions are shown [2]

3.3 Hand-held scanners

Hand-held laser scanners create a 3D image through the triangulation mechanism described above: a laser dot or line is projected onto an object from a hand-held device and a sensor (typically a charge-coupled device or position sensitive device) measures the distance to the surface. Data is collected in relation to an internal coordinate system and therefore to collect data where the scanner is in motion the position of the scanner must be determined. The position can be determined by the scanner using reference features on the surface being scanned (typically adhesive reflective tabs, but natural features have been also used in research work) or by using an external tracking method. External tracking often takes the form of a laser tracker (to provide the sensor position) with integrated camera (to determine the orientation of the scanner) or a photogrammetric solution using 3 or more cameras providing the complete six degrees of freedom of the scanner. Both techniques tend to use infra red light-emitting diodes attached to the scanner which are seen by the camera(s) through filters providing resilience to ambient lighting.

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Data is collected by a computer and recorded as data points within three-dimensional space, with processing this can be converted into a triangulated mesh and then a computer-aided design model, often as non-uniform rational B-spline surfaces. Hand-held laser scanners can combine this data with passive, visible-light sensors — which capture surface textures and colours - to build (or "reverse engineer") a full 3D model.

3.4 Structured light

Structured-light 3D scanners project a pattern of light on the subject and look at the deformation of the pattern on the subject. The pattern is projected onto the subject using either an LCD projector or other stable light source. A camera, offset slightly from the pattern projector, looks at the shape of the pattern and calculates the distance of every point in the field of view.

Structured-light scanning is still a very active area of research with many research papers published each year. Perfect maps have also been proven useful as structured light patterns that solve the correspondence problem and allow for error detection and error correction. The advantage of structured-light 3D scanners is speed and precision. Instead of scanning one point at a time, structured light scanners scan multiple points or the entire field of view at once. Scanning an entire field of view in a fraction of a second reduces or eliminates the problem of distortion from motion. Some existing systems are capable of scanning moving objects in real-time. VisionMaster creates a 3D scanning system with a 5-megapixel camera – 5 million data points are acquired in every frame.

A real-time scanner using digital fringe projection and phase-shifting technique (certain kinds of structured light methods) was developed, to capture, reconstruct, and render high-density details of dynamically deformable objects (such as facial expressions) at 40 frames per second. Recently, another scanner has been developed. Different patterns can be applied to this system, and the frame rate for capturing and data processing achieves 120 frames per second. It can also scan isolated surfaces, for example two moving hands. By utilising the binary defocusing technique, speed breakthroughs have been made that could reach hundreds of to thousands of frames per second.

3.5 Modulated light

Modulated light 3D scanners shine a continually changing light at the subject. Usually the light source simply cycles its amplitude in a sinusoidal pattern. A camera detects the reflected light and the amount the pattern is shifted by determines the distance the light travelled. Modulated light also allows the scanner to ignore light from sources other than a laser, so there is no interference.

3.6 Non-contact passive

Passive 3D imaging solutions do not emit any kind of radiation themselves, but instead rely on detecting reflected ambient radiation. Most solutions of this type detect visible light because it is a readily available ambient radiation. Other types of radiation, such as infra red could also be used. Passive methods can be very cheap, because in most cases they do not need particular hardware but simple digital cameras.

- Stereoscopic systems usually employ two video cameras, slightly apart, looking at the same scene. By analysing the slight differences between the images seen by each camera, it is possible to determine the distance at each point in the images. This method is based on the same principles driving human stereoscopic vision.
- Photometric systems usually use a single camera, but take multiple images under varying lighting conditions. These techniques attempt to invert the image formation model in order to recover the surface orientation at each pixel.
- Silhouette techniques use outlines created from a sequence of photographs around a three-dimensional object against a well contrasted background. These silhouettes are extruded and intersected to form the visual hull approximation of the object. With these approaches some concavities of an object (like the interior of a bowl) can not be detected.

4 Reconstruction**4.1 From point clouds**

A point cloud is a set of data points in space. Point clouds are generally produced by 3D scanners, which measure a large number of points on the external surfaces of objects around them. As the output of 3D scanning processes, point clouds are used for many purposes, including to create 3D CAD models for manufactured parts, for metrology and quality inspection, and for a multitude of visualization, animation, rendering and mass customization applications.

4.1.1 Alignment and registration

Point clouds are often aligned with 3D models or with other point clouds, a process known as point set registration.

For industrial metrology or inspection using industrial computed tomography, the point cloud of a manufactured part can be aligned to an existing model and compared to check for differences. Geometric dimensions and tolerances can also be extracted directly from the point cloud (Figure 4).

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Figure 4 Point cloud of Red Rocks, Colorado

4.1.2 Conversion to the 3D surfaces

While point clouds can be directly rendered and inspected, point clouds are often converted to polygon mesh or triangle mesh models or CAD models through a process commonly referred to as surface reconstruction.

There are many techniques for converting a point cloud to a 3D surface. Some approaches, like Delaunay triangulation, alpha shapes, and ball pivoting, build a network of triangles over the existing vertices of the point cloud, while other approaches convert the point cloud into a volumetric distance field and reconstruct the implicit surface so defined through a marching cubes algorithm.

In geographic information systems, point clouds are one of the sources used to make digital elevation model of the terrain. They are also used to generate 3D models of urban environments.

Point clouds can also be used to represent volumetric data, as is sometimes done in medical imaging (Figure 5). Using point clouds, multi-sampling and data compression can be achieved.



Figure 5 Point cloud

4.2 From models

Most applications, however, use instead polygonal 3D models, NURBS surface models, or editable feature-based CAD models (aka Solid models).

- Polygon mesh models:** In a polygonal representation of a shape, a curved surface is modeled as many small faceted flat surfaces (think of a sphere modeled as a disco ball). Polygon models—also called Mesh models—are useful for visualisation, for some CAM (i.e., machining), but are generally "heavy" (i.e., very large data sets), and are relatively un-editable in this form (Figure 6). Reconstruction to polygonal model involves finding and connecting adjacent points with straight lines in order to create a continuous surface. Many applications, both free and nonfree, are available for this purpose (e.g. MeshLab, PointCab, kubit PointCloud for AutoCAD, JRC 3D Reconstructor, imagemodel, PolyWorks, Rapidform, Geomagic, Imageware, Rhino 3D etc.).
- Surface models:** The next level of sophistication in modeling involves using a quilt of *curved* surface patches to model the shape. These might be NURBS, TSplines or other curved representations of curved topology. Using NURBS, the spherical shape becomes a true mathematical sphere. Some applications offer patch layout by hand but the best in class offer both automated patch layout and manual layout. These patches have the advantage of being lighter and more manipulable when exported to CAD. Surface models are somewhat editable, but only in a sculptural sense of pushing and pulling to deform the surface. This representation lends itself well to modelling organic and artistic shapes. Providers of surface modellers include Rapidform, Geomagic, Rhino 3D, Maya, T Splines etc.
- Solid CAD models:** From an engineering/manufacturing perspective, the ultimate representation of a digitised shape is the editable, parametric CAD model. In CAD, the sphere is described by parametric features which are easily edited by changing a value (e.g., centre point and radius).

These CAD models describe not simply the envelope or shape of the object, but CAD models also embody the "design intent" (i.e., critical features and their relationship to other features). An example of design intent not evident in the shape alone might be a brake drum's lug bolts, which must be concentric with the hole in the centre of the drum. This knowledge would drive the sequence and method of creating the CAD model; a designer with an awareness of this relationship would not design the lug bolts referenced to the outside diameter, but instead, to the centre [3-5]. A modeler creating a CAD model will want to include both Shape and design intent in the complete CAD model.

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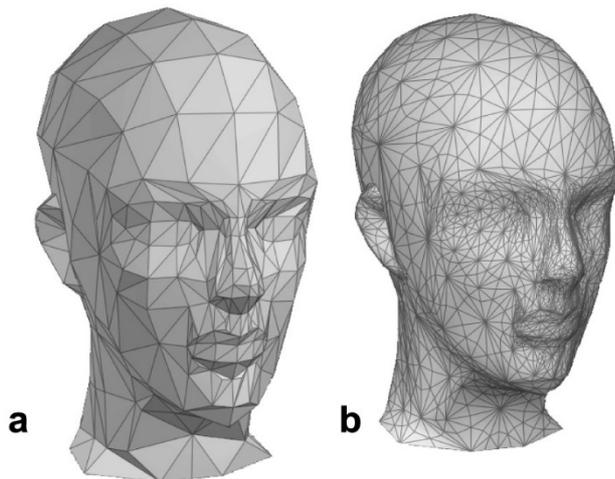


Figure 6 Polygon mesh model of human head

4.3 From laser scans

Laser scanning describes the general method to sample or scan a surface using laser technology. Several areas of application exist that mainly differ in the power of the lasers that are used, and in the results of the scanning process. Low laser power is used when the scanned surface doesn't have to be influenced, e.g. when it only has to be digitised. Confocal or 3D laser scanning are methods to get information about the scanned surface. Another low-power application uses structured light projection systems for solar cell flatness metrology [6], enabling stress calculation throughout in excess of 2000 wafers per hour [7].

The laser power used for laser scanning equipment in industrial applications is typically less than 1W. The power level is usually on the order of 200 mW or less but sometimes more.

5 Conclusion

Nowadays scanning technology is moving extremely forward. We can see a number of different scanning devices on the market that have a specific specification and use. The use of scanners in today's industry and other industries is very much needed. In the field of medicine, construction, energetics or engineering. Scanning process is more widespread and is also gaining new industries. The acquisition of the digital form of various historical buildings or other objects also has the merit of maintaining history.

Acknowledgement

This article was created by implementation of the grant project APVV-17-0258 Digital engineering elements application in innovation and optimization of production flows.

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Review process

Single-blind peer review process.



JOURNAL STATEMENT

Journal name:	Acta Simulatio
Abbreviated key title:	Acta Simul
Journal title initials:	AS
Journal doi:	10.22306/asim
ISSN:	1339-9640
Start year:	2015
The first publishing:	March 2015
Issue publishing:	Quarterly
Publishing form:	On-line electronic publishing
Availability of articles:	Open Access Journal
Journal license:	CC BY-NC
Publication ethics:	COPE, ELSEVIER Publishing Ethics
Plagiarism check:	Worldwide originality control system
Peer review process:	Single-blind review at least two reviewers
Language:	English
Journal e-mail:	info@actasimulatio.eu

The journal focuses mainly on the original and new, interesting, high-quality, theoretical, practical and application-oriented contributions to the field of science and research as well as to pedagogy and education in the area of simulation.

Publisher:	4S go, s.r.o.
Address:	Semsa 24, 044 21 Semsa, Slovak Republic, EU
Phone:	+421 948 366 110
Publisher e-mail:	info@4sgo.eu

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