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Use of a tool to create a continuous surface. Many applications, both free and nonfree, are available for this purpose (e.g. GigaMesh, MeshLab, PointCab, kubit PointCloud for AutoCAD, Reconstructor, imagemodel, PolyWorks, Rapidform, Geomagic, Imageware, Rhino 3D etc.). Surface models: The next level of sophistication in modeling involves creating a curved surface patches to model the shape. These can be NURBS, T-Splines or other curved representations of curved topology. Using NURBS, the spherical shape becomes a true mathematical sphere. Some applications offer patch layout tools, but the best in class offer both multi-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 center. A modeler creating a CAD model will want to include both Shape and design intent in the complete CAD model. Vendors offer different approaches to getting to the parametric CAD model. Some export the NURBS surfaces and leave it to the CAD designer to complete the model in CAD (e.g., Geomagic, Imageware, Rhino 3D). Others use the scan data to create an editable and verifiable feature based model that is imported into CAD with full feature tree intact, yielding a complete, native CAD model, capturing both shape and design intent (e.g., Geomagic, Rapidform). For instance, the market offers various plug-ins for established CAD-programs, such as SolidWorks, Xtract3D, DesignWorks and Geomagic for SolidWorks allow manipulating a 3D scan directly inside SolidWorks. Still other CAD applications are robust enough to manipulate limited points or polygon models within the CAD environment (e.g., CATIA, AutoCAD, Revit). 3D reconstruction of the brain and eyeballs from CT scanner DICOM images. In this image, areas with the density of bone or air were made transparent, and the slices stacked, giving an approximate free-space alignment. The outer ring of material around the brain are the soft tissues of skin and muscle on the outside of the skull. black box encloses the slices to provide the black background. Since these are simply 2D images stacked on top when viewed on edge the slices disappear since they have effectively zero thickness. Each DICOM scan represents about 5 mm of material averaged into a thin slice. CT, industrial CT, MRI, or micro-CT scanners do not produce point clouds but a set of 2D slices (each termed a "tomogram") which are then "stacked together" to produce a 3D representation. There are several ways to do this depending on the output required: Volume rendering; Different parts of an object usually have different threshold values or greyscale densities. From this, a 3-dimensional model can be constructed and displayed on screen. Multiple models can be constructed from various thresholds, allowing different colors to represent each component of the object. Volume rendering is usually only used for visualisation of the scanned object. Image segmentation: Where different structures have similar threshold/greyscale values, it can become impossible to separate them simply by adjusting volume rendering parameters. The solution is called segmentation, a manual or automatic procedure that can remove the unwanted structures from the image. Image segmentation software usually allows export of the segmented structures in CAD or STL format for further manipulation. Image-based meshing: When using 3D image data for computational analysis (e.g. CFD and FEA), simply segmenting the data and meshing from CAD can become time-consuming, and virtually intractable for the complex topologies typical of image data. The solution is called image-based meshing, an automated process of generating an accurate and realistic geometrical description of the scan data. 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 digitized. 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 measurement.[41] enabling stress calculation throughout in excess of 2000 video frames per hour.[42] 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. See also: Photogrammetry 3D data acquisition and object reconstruction can be performed using stereo image pairs. Stereo photogrammetry or photogrammetry based on a block of overlapped images is the primary approach for 3D mapping and object reconstruction using 2D images. Close-range photogrammetry has also matured to the level where cameras or digital cameras can be used to capture the close-look images of objects, e.g., buildings, and reconstruct them using the very same theory as the aerial photogrammetry. An example of software which could do this is Vexcel FotoG 5.[43][44] This software has now been replaced by Vexcel GeoSynth.[45] Another similar software program is Microsoft Photosynth.[46][47] A semi-automatic method for acquiring 3D topologically structured data from 2D aerial stereo images has been presented by Sisi Zlatanova.[48] The process involves the manual digitizing of a number of points necessary for automatically reconstructing the 3D objects. Each reconstructed object is validated by superimposition of its wire frame graphics in the stereo model. The topologically structured 3D data is stored in a database and are also used for visualization of the objects. Notable software used for 3D data acquisition using 2D images include e.g. Agisoft Metashape,[49] RealityCapture,[50] and ENSAIS Engineering College TIPHON (Traitement d'Image et PHotogrammétrie Numérique).[51] A hybrid for semi-automatic building extraction together with a concept for storing building models alongside terrain and other topographic data in a topographical information system has been developed by Franz Rottensteiner. His approach was based on the integration of building parameter estimations into the photogrammetry process applying a hybrid modeling scheme. Buildings are decomposed into a set of simple primitives that are reconstructed individually and are then combined by Boolean operators. The internal data structure of both the primitives and the compound building models are based on the boundary representation method.[52][53] Multiple images are used in Zhang's[54] approach to surface reconstruction from multiple images. A central idea is to explore the integration of both 3D stereo data and 2D calibrated images. This approach is motivated by the fact that only robust and accurate feature points that survived the geometry scrutiny of multiple images are reconstructed in space. The density insufficiency and the inevitable holes in the stereo data should then be filled in by using information from multiple images. The idea is thus to first construct small surface patches from stereo points, then to progressively propagate only reliable patches in their neighborhood from images into the whole surface using a best-first strategy. The problem thus reduces to searching for an optimal local surface patch going through a given set of stereo points from images. Multi-spectral images are also used for 3D building detection. The first and last pulse data and the normalized difference vegetation index are used in the process.[55] New measurement techniques are also employed to obtain measurements and between objects from single images by using the projection, or the shadow as well as their combination. This technology is gaining attention given its fast processing time, and far lower cost than stereo measurements.[citation needed] 3D scanning technology has been used to scan space rocks for the European Space Agency.[56][57] Robotic control: e.g. a laser scanner may function as the "eye" of a robot.[58][59] As-built drawings of bridges, industrial plants, and monuments Documentation of historical sites[60] Site modelling and lay outting Quality control Quality surveys Payload monitoring [61] Freeview redesign Establishing a bench mark of pre-existing shape/state in order to detect structural changes resulting from exposure to extreme loadings such as earthquake, vesse/truck impact or fire. Create GIS (geographic information system) maps[62] and geomatics. Subsurface laser scanning in mines and karst voids.[63] Forensic documentation[64] Increasing accuracy working with complex parts and shapes, Coordinating product design using parts from multiple sources, Updating old CD scans with those from more current technology, Replacing missing or older parts, Creating cost savings by allowing as-built design services, for example in automotive manufacturing plants, "Bringing the plant to the engineers" with web shared scans, and Saving travel costs. 3D scanners are used by the entertainment industry to create digital 3D models for movies, video games and leisure purposes.[65] They are heavily utilized in virtual cinematography. In cases where a real-world equivalent of a model exists, it is much faster to scan the real-world object than to manually create a model using 3D modeling software. Frequently, artists sculpt physical models of what they want and scan them into digital form rather than directly creating digital models on a computer. 3D selfie in 1:20 scale printed by Shapeways using gypsum-based printing, created by Madurodam miniature park from 2D pictures taken at its Fantastiron photo booth Fantastiron 3D photo booth at Madurodam 3D scanners are evolving for the use of cameras to represent 3D objects in an accurate manner.[66] Companies are emerging since 2010 that create 3D portraits of people (3D figurines or 3D selfie). An augmented reality menu for the Madrid restaurant chain 80 Degrees[67] 3D laser scanning is used by the law enforcement agencies around the world. 3D models are used for on-site documentation of:[68] Crime scenes Buld trajectories Bloodstain pattern analysis Accident reconstruction Bombings Plane crashes, and more Reverse engineering of a mechanical component requires a precise digital model of the object to be reproduced. Rather than a set of points a precise digital model can be represented by a polygon mesh, a set of lat or curved NURBS surfaces, or ideally for mechanical components, a CAD solid model. A 3D scanner can be used to digitise free-form or gradually changing shaped components as well as prismatic geometries whereas a coordinate measuring machine is usually used only to determine simple dimensions of a highly prismatic model. These data points are then processed to create a usable digital model, usually using specialized reverse engineering software. Land or buildings can be scanned into a 3D model, which allows buyers to tour and inspect the property remotely, anywhere, without having to be present at the property.[69] There is already at least one company providing 3D scanned virtual real estate tours.[70] A typical virtual tour Archived 2017-04-27 at the Wayback Machine would consist of dollhouse view,[71] inside view, as well as a floor plan. The environment a place of interest can be captured and converted into a 3D model. This model can then be explored by the public, either through a VR interface or a traditional "2D" interface. This allows the user to explore locations which are inconvenient for travel.[72] A group of history students at Vancouver ITeCh Preparatory Middle School created a Virtual Museum by 3D Scanning more than 100 artifacts.[73] There have been many research projects undertaken via the scanning of historical sites and artifacts both for documentation and analysis purposes.[74] The resulting models can be used for a variety of different analytical approaches.[75][76] The combined use of 3D scanning and 3D printing technologies allows the replication of real objects without the use of traditional plaster casting techniques, that in many cases can be too invasive for being performed on precious or delicate cultural heritage artifacts.[77] In an example of a typical application scenario, a gargoyle model was digitally acquired using a 3D scanner and the produced 3D data was processed using MeshLab. 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CAD/CAM software are then used to design and manufacture the orthosis, prosthesis[93] or dental implants. Many chairside dental CAD/CAM systems and dental laboratory CAD/CAM systems use 3D scanner technologies to capture the 3D surface of a dental preparation (either in vivo or in vitro), in order to produce a restoration digitally using CAD software and ultimately produce the final restoration using a CAM technology (such as a CNC milling machine, or 3D printer). The chairside systems are designed to facilitate the 3D scanning of a preparation in vivo and produce the restoration (such as a Crown, Onlay, Inlay or Veneer). Creation of 3D models for anatomy and biology education[94][95] and cadaver models for educational neurosurgical simulations.[96] The digitisation of real-world objects is of vital importance in various application domains. 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For this purpose, 3D scanners are applied to generate point samples from the object's surface which are finally compared against the nominal data.[97] The process of comparing 3D data against a CAD model is referred to as CAD-Compare, and can be a useful technique for applications such as determining wear patterns on moulds and tooling, determining accuracy of final build, analysing gap and flush, or analysing highly complex sculpted surfaces. At present, laser triangulation scanners, structured light and contact scanning are the predominant technologies employed for industrial purposes, with contact scanning remaining the slowest, but overall most accurate option. Nevertheless, 3D scanning technology offers distinct advantages compared to traditional touch probe measurements. White-light or laser scanners accurately digitize objects all around, capturing fine details and freeform surfaces without reference points or spray. The entire surface is covered at record speed without the risk of damaging the part. Graphic comparison charts illustrate geometric deviations of full object level, providing deeper insights into potential causes.[98][99] Main article: 3D reconstruction See also: 3D reconstruction from multiple images After reconstructed 2017-04-27 at the Wayback Machine would consist of dollhouse view,[71] inside view, as well as a floor plan. The environment a place of interest can be captured and converted into a 3D model. This model can then be explored by the public, either through a VR interface or a traditional "2D" interface. 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The entire surface is covered at record speed without the risk of damaging the part. Graphic comparison charts illustrate geometric deviations of full object level, providing deeper insights into potential causes.[98][99] Main article: 3D reconstruction See also: 3D reconstruction from multiple images After reconstructed 2017-04-27 at the Wayback Machine would consist of dollhouse view,[71] inside view, as well as a floor plan. The environment a place of interest can be captured and converted into a 3D model. This model can then be explored by the public, either through a VR interface or a traditional "2D" interface. This allows the user to explore locations which are inconvenient for travel.[72] A group of history students at Vancouver ITeCh Preparatory Middle School created a Virtual Museum by 3D Scanning more than 100 artifacts.[73] There have been many research projects undertaken via the scanning of historical sites and artifacts both for documentation and analysis purposes.[74] The resulting models can be used for a variety of different analytical approaches.[75][76] The combined use of 3D scanning and 3D printing technologies allows the replication of real objects without the use of traditional plaster casting techniques, that in many cases can be too invasive for being performed on precious or delicate cultural heritage artifacts.[77] In an example of a typical application scenario, a gargoyle model was digitally acquired using a 3D scanner and the produced 3D data was processed using MeshLab. The resulting digital 3D model was fed to a rapid prototyping machine to create a real resin replica of the original object. Creation of 3D models for Museums and Archaeological artifacts[78][79][80] In 1999, two different research groups started scanning Michelangelo's statues. Stanford University with a group led by Marc Levoy[81] used a custom laser triangulation scanner built by Cyberwave to scan Michelangelo's statues in Florence, notably the David, the Prigioni and the four statues in The Medici Chapel. The scans produced a data point density of one sample per 0.25 mm, detailed enough to see Michelangelo's chisel marks. These detailed scans produced a large amount of data (up to 32 gigabytes) and processing the data from his scans took 5 months. Approximately in the same period a research group from IBM, led by H. Rushmeier and F. Bernardini scanned the Pietà of Florence acquiring both geometric and color details. The digital model, result of the Stanford scanning campaign, was thoroughly used in the subsequent restoration of the statue.[82] In 2002, David Luebke, et al. scanned Thomas Jefferson's Monticello.[83] A commerial team of flight laser scanner, the DeltaSphere 3000, was used. The scanner data was then combined with color data from digital photographs to create the Virtual Monticello, and the Jefferson's Cabinet exhibits in the New Orleans Museum of Art in 2003. The Virtual Monticello exhibit simulated a window looking into Jefferson's Library. The exhibit consisted of a rear projection display on a wall and a pair of stereo glasses for the viewer. The glasses, combined with polarised projectors, provided a 3D effect. Position tracking hardware on the glasses allowed the display to adapt as the viewer moves around, creating the illusion that the display is actually a hole in the wall looking into Jefferson's Library. The Jefferson's Cabinet exhibit was a barrier stereogram (essentially a non-active hologram that appears different from different angles) of Jefferson's Cabinet. The first 3D models of coneiform tablets were acquired in Germany in 2000.[84] In 2003 the so-called Digital Hammurabi project acquired coneiform tablets with a laser triangulation scanner using a regular grid pattern having a resolution of 0.025 mm (0.00098 in).[85] With the use of high-resolution 3D scanners by the Heidelberg University for tablet acquisition in 2009 the development of the GigaMesh Software Framework began to visualize and extract coneiform characters from 3D models.[86] It was used to process ca. 2.000 3D digitized tablets of the Hilprecht Collection in Jena to create an Open Access benchmark dataset[87] and an annotated collection[88] of 3D models of tablets freely available under CC BY licenses.[89] A 2009 CyArk 3D scanning project at Uganda's historic Kasubi Tombs, a UNESCO World Heritage Site, using a Leica HDS 4500, produced detailed architectural models of Muzibu Azaala Mpanga, the main building at the complex and tomb of the Kabakas (Kings) of Uganda. A fire on March 16, 2010, burned down much of the Muzibu Azaala Mpanga structure, and reconstruction work is likely to lean heavily upon the dataset produced by the 3D scan mission.[90] In 2005, Gabriele Guidi, et al. scanned the "Plastico di Roma antica" [91] a model of Rome created in the last century. Neither the triangulation method, nor the time of flight method satisfied the requirements of this project because the item to be scanned was both large and contained small details. They found though that a modulated light scanner was able to provide both the ability to scan an object the size of the model and the accuracy that was needed. The modulated light scanner was supplemented by a triangulation scanner which was used to scan some parts of the model. The 3D Encounters Project at the Petrie Museum of Egyptian Archaeology aims to use 3D laser scanning to create a high quality 3D image library of artefacts and enable digital travelling exhibitions of fragile Egyptian artefacts. English Heritage has investigated the use of 3D laser scanning for a wide range of applications to gain archaeological and condition data, and the National Conservation Centre in Liverpool has also produced 3D laser scans on commission, including portable object and in situ scans of archaeological sites.[92] The Smithsonian Institution has a project called Smithsonian X 3D notable for the breadth of types of 3D objects they are attempting to scan. These include small objects such as insects and flowers, to human sized objects such as Amelia Earhart's Flight Suit to room sized objects such as the Gunboat Philadelphia to historic sites such as Liang Bua in Indonesia. Also of note the data from these scans is being made available to the public for free and downloadable in several data formats. 3D scanners are used to capture the 3D shape of a patient in orthotics and dentistry. It gradually supplants tedious plaster cast. 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