Digitization techniques pdf

Converting information into digital form "Digitizer" redirects here. For other uses, see Digitizer (disambiguation). For transforming business and education, see Digital transformation.For the shift from mechanical and analog electronic technology to digital electronics technology, see Digital Revolution. Internet Archive book scanner Digitization[1] is the process of converting information into a digital (i.e. computer-readable) format.[2] The result is the representation of an object, image, sound, document, or signal (usually an analog signal) obtained by generating a series of numbers that describe a discrete set of points or samples. The result is called digital representation or, more specifically, a digital image, for the object, and digital form, for the signal. In modern practice, the digitized data is in the form of binary numbers, which facilitates processing by digital computers and other operations, but digitizing simply means "the conversion of analog source material into a numerical format"; the decimal or any other number system can be used instead.[3] Digitization is of crucial importance to data processing, storage, and transmission, because it "allows information of all kinds in all formats to be carried with the same efficiency and also intermingled."[4] Though analog data is typically more stable, digital data has the potential to be more easily shared and accessed and, in theory, can be propagated indefinitely without generation loss, provided it is migrated to new, stable formats as needed.[5] This potential has led to institutional digitization projects designed to improve access and the rapid growth of the digital preservation field.[6] Sometimes digitization and digital preservation are mistaken for the same thing. They are different, but digitization is often a vital first step in digital preservation.[7] Libraries, archives, museums, and other memory institutions digitize items to preserve fragile materials and create more access points for patrons.[8] Doing this creates challenges for information professionals and solutions can be as varied as the institutions that implement them.[9] Some analog materials, such as audio and video tapes, are nearing the end of their life-cycle, and it is important to digitize them before equipment obsolescence and media deterioration makes the data irretrievable.[10] There are challenges and implications surrounding digitization including time, cost, cultural history concerns, and creating an equitable platform for historically marginalized voices.[11] Many digitizing institutions develop their own solutions to these challenges.[8] Mass digitization projects have had mixed results over the years, but some institutions have had success even if not in the traditional Google Books model.[12] Technological changes can happen often and quickly, so digitization standards are difficult to keep updated. Professionals in the field can attend conferences and join organizations and working groups to keep their knowledge current and add to the conversation.[13] Process The term digitization is often used when diverse forms of information, such as an object, text, sound, image, or voice, are converted into a single binary code. The core of the process is the compromise between the capturing device and the player device so that the rendered result represents the original source with the most possible fidelity, and the advantage of digitization is the speed and accuracy in which this form of information can be transmitted with no degradation compared with analog information. Digital information exists as one of two digits, either 0 or 1. These are known as bits (a contraction of binary digits) and the sequences of 0s and 1s that constitute information are called bytes.[14] Analog signals are continuously variable, both in the number of possible values of the signal at a given time, as well as in the number of points in the signal in a given period of time. However, digital signals are discrete in both of those respects – generally a finite sequence of integers – therefore a digitization can, in practical terms, only ever be an approximation of the signal it represents. Digitization occurs in two parts: Discretization The reading of an analog signal A, and, at regular time intervals (frequency), sampling the value of the signal at the point. Each such reading is called a sample and may be considered to have infinite precision at this stage; Quantization Samples are rounded to a fixed set of numbers (such as integers), a process known as quantization. In general, these can occur at the same time, though they are conceptually distinct. A series of digital integers can be transformed into an analog output that approximates the original analog signal. Such a transformation is called a DA conversion. The sampling rate and the number of bits used to represent the integers combine to determine how close such an approximation to the analog signal a digitization will be. Examples Digitization of the first number of Estonian popular science magazine Horisont published in January 1967. The term is used to describe, for example, the scanning of analog sources (such as printed photos or taped videos) into computers for editing, 3D scanning that creates 3D modeling of an object's surface, and audio (where sampling rate is often measured in kilohertz) and texture map transformations. In this last case, as in normal photos, the sampling rate refers to the resolution of the image, often measured in pixels per inch. Digitizing is the primary way of storing images in a form suitable for transmission and computer processing, whether scanned from two-dimensional analog originals or captured using an image sensor-equipped device such as a digital camera, tomographical instrument such as a CAT scanner, or acquiring precise dimensions from a real-world object, such as a car, using a 3D scanning device.[15] Digitizing is central to making digital representations of geographical features, using raster or vector images, in a geographic information system, i.e., the creation of electronic maps, either from various geographical and satellite imaging (raster) or by digitizing traditional paper maps or graphs (vector).[citation needed] "Digitization" is also used to describe the process of populating databases with files or data. While this usage is technically inaccurate, it originates with the previously proper use of the term to describe that part of the process involving digitization of analog sources, such as printed pictures and brochures, before uploading to target databases. Digitizing may also be used in the field of apparel, where an image may be recreated with the help of embroidery digitizing software tools and saved as embroidery machine code. This machine code is fed into an embroidery machine and applied to the fabric. The most supported format is DST file. Apparel companies also digitize clothing patterns.[citation needed][16] History 1957 The Standards Electronic Automatic Computer (SEAC) was invented.[17] That same year, Russell Kirsch used a rotating drum scanner and photomultiplier connected to SEAC to create the first digital image (176x176 pixels) from a photo of his infant son.[18][19] This image was stored in SEAC memory via a staticizer and viewed via a cathode ray oscilloscope.[20][19] 1971 Invention of Charge-Coupled Devices that made conversion from analog data to a digital format easy.[17] 1986 work started on the JPEG format.[17] 1990s Libraries began scanning collections to provide access via the world wide web.[21] Analog signals to digital Analog signals are continuous electrical signals; digital signals are non-continuous. Analog signals can be converted to digital signals by using an analog-to-digital converter.[22] The process of converting analog to digital consists of two parts: sampling and quantizing. Sampling measures wave amplitudes at regular intervals, splits them along the vertical axis, and assigns them a numerical value, while quantizing looks for measurements that are between binary values and rounds them up or down.[23] Nearly all recorded music has been digitized, and about 12 percent of the 500,000+ movies listed on the Internet Movie Database are digitized and were released on DVD.[24][25] Digitization of home movies, slides, and photographs is a popular method of preserving and sharing personal multimedia. Slides and photographs may be scanned quickly using an image scanner, but analog video requires a video tape player to be connected to a computer while the item plays in real time.[26][27] Slides can be digitized quicker with a slide scanner such as the Nikon Coolscan 5000ED.[28] Another example of digitization is the VisualAudio process developed by the Swiss Fonoteca Nazionale in Lugano, by scanning a high resolution photograph of a record, they are able to extract and reconstruct the sound from the processed image.[29] Digitization of analog tapes before they degrade, or after damage has already occurred, can rescue the only copies of local and traditional cultural music for future generations to study and enjoy.[30][31] Analog texts to digital Main article: Book digitization Further information: Text digitizing projects Book scanner in the digitization lab at the University of Liège, Belgium. Academic and public libraries, foundations, and private companies like Google are scanning older print books and applying optical character recognition (OCR) technologies so they can be keyword searched, but as of 2006, only about 1 in 20 texts had been digitized.[32] Librarians and archivists are working to increase this statistic and in 2019 began digitizing 480,000 books published between 1923 and 1964 that had entered the public domain.[33] Unpublished manuscripts and other rare papers and documents housed in special collections are being digitized by libraries and archives, but backlogs often slow this process and keep materials with enduring historical and research value hidden from most users (see digital libraries).[34] Digitization has not completely replaced other archival imaging options, such as microfilming which is still used by institutions such as the National Archives and Records Administration (NARA) to provide preservation and access to these resources.[35][36] While digital versions of analog texts can potentially be accessed from anywhere in the world, they are not as stable as most print materials or manuscripts and are unlikely to be accessible decades from now without further preservation efforts, while many books manuscripts and scrolls have already been around for centuries.[37] However, for some materials that have been damaged by water, insects, or catastrophes, digitization might be the only option for continued use.[38] Library preservation Main article: Preservation (library and archival science) Digitization at the British Library of a Dunhuang manuscript for the International Dunhuang Project In the context of libraries, archives, and museums, digitization is a means of creating digital surrogates of analog materials, such as books, newspapers, microfilm and videotapes, offers a variety of benefits, including increasing access, especially for patrons at a distance; contributing to collection development, through collaborative initiatives; enhancing the potential for research and education; and supporting preservation activities.[39] Digitization can provide a means of preserving the content of the materials by creating an accessible facsimile of the object in order to put less strain on already fragile originals. For sounds, digitization of legacy analog recordings is essential insurance against technological obsolescence.[40] A fundamental aspect of planning digitization projects is to ensure that the digital files themselves are preserved and remain accessible;[41] the term "digital preservation," in its most basic sense, refers to an array of activities undertaken to maintain access to digital materials over time.[42] The prevalent Brittle Books issue facing libraries across the world is being addressed with a digital solution for long term book preservation.[43] Since the mid-1800s, books were printed on wood-pulp paper, which turns acidic as it decays. Deterioration may advance to a point where a book is completely unusable. In theory, if these widely circulated titles are not treated with de-acidification processes, the materials upon those acid pages will be lost. As digital technology evolves, it is increasingly preferred as a method of preserving these materials, mainly because it can provide easier access points and significantly reduce the need for physical storage space. Cambridge University Library is working on the Cambridge Digital Library, which will initially contain digitised versions of many of its most important works relating to science and religion. These include examples such as Isaac Newton's personally annotated first edition of his Philosophiæ Naturalis Principia Mathematica[44] as well as college notebooks[45][46] and other papers,[47] and some Islamic manuscripts such as a Quran[48] from Tipu Sahib's library. Google, Inc. has taken steps towards attempting to digitize every title with "Google Book Search".[49] While some academic libraries have been contracted by the service, issues of copyright law violations threaten to derail the project.[50] However, it does provide – at the very least – an online consortium for libraries to exchange information and for researchers to search for titles as well as review the materials. Digitization versus digital preservation Main article: Digital preservation Digitizing something is not the same as digitally preserving it.[51] To digitize something is to create a digital surrogate (copy or format) of an existing analog item (book, photograph, or record) and is often described as converting it from analog to digital, however both copies remain.[52][53] An example would be scanning a photograph and having the original piece in a photo album and a digital copy saved to a computer. This is essentially the first step in digital preservation which is to maintain the digital copy over a long period of time and making sure it remains authentic and accessible.[54][51][55] Digitization is done once with the technology currently available, while digital preservation is more complicated because technology changes so quickly that a once popular storage format may become obsolete before it breaks.[55] An example is a 5 1/4" floppy drive, computers are no longer made with them and obtaining the hardware to convert a file stored on 5 1/4" floppy disc can be expensive. To combat this risk, equipment must be upgraded as newer technology becomes affordable (about 2 to 5 years), but before older technology becomes unobtainable (about 5 to 10 years).[56][55] Digital preservation can also apply to born-digital material, such as a Microsoft Word document or a social media post.[57] In contrast, digitization only applies exclusively to analog materials. Born-digital materials present a unique challenge to digital preservation not only due to technological obsolescence but also because of the inherently unstable nature of digital storage and maintenance.[55] Most websites last between 2.5 and 5 years, depending on the purpose for which they were designed.[58] The Library of Congress provides numerous resources and tips for individuals looking to practice digitization and digital preservation for their personal collections.[59] Digital reformatting Digital reformatting is the process of converting analog materials into a digital format as a surrogate of the original. The digital surrogates perform a preservation function by reducing or eliminating the use of the original. Digital reformatting is guided by established best practices to ensure that materials are being converted at the highest quality. Digital reformatting at the Library of Congress The Library of Congress has been actively reformatting materials for its American Memory project and developed best standards and practices pertaining to book handling during the digitization process, scanning resolutions, and preferred file formats.[60] Some of these standards are: The use of ISO 16067-1 and ISO 16067-2 standards for resolution requirements. Recommended 400 ppi resolution for OCR'ed printed text. The use of 24-bit color when color is an important attribute of a document. The use of the scanning device's maximum resolution for digitally reproducing photographs TIFF as the standard file format. Attachment of descriptive, structural, and technical metadata to all digitized documents. A list of archival standards for digital preservation can be found on the ARL website.[61] The Library of Congress has constituted a Preservation Digital Reformatting Program.[62] The Three main components of the program include: Selection Criteria for digital reformatting Digital reformatting principles and specifications Life cycle management of LC digital data Audio digitization and reformatting Audio media offers a rich source of historic ethnographic information, with the earliest forms of recorded sound dating back to 1890.[63] According to the International Association of Sound and Audiovisual Archives (IASA), these sources of audio data, as well as the aging technologies used to play them back, are in imminent danger of permanent loss due to degradation and obsolescence.[64] These primary sources are called "carriers" and exist in a variety of formats, including wax cylinders, magnetic tape, and flat discs of grooved media, among others. Some formats are susceptible to more severe, or quicker, degradation than others. For instance, lacquer discs suffer from delamination. Analog tape may deteriorate due to sticky shed syndrome.[65] 1/4" analog tape being played back on a Studer A810 tape machine for digitization at Smithsonian Folkways Recordings. Archival workflow and file standardization have been developed to minimize loss of information from the original carrier to the resulting digital file as digitization is underway. For most at-risk formats (magnetic tape, grooved cylinders, etc.), a similar workflow can be observed. Examination of the source carrier will help determine what, if any, steps need to be taken to repair material prior to transfer. A similar inspection must be undertaken for the playback machines. If satisfactory conditions are met for both carrier and playback machine, the transfer can take place, moderated by an analog-to-digital converter.[66] The digital signal is then represented visually for the transfer engineer by a digital audio workstation, like Audacity, WaveLab, or Pro Tools. Reference access copies can be made at smaller sample rates. For archival purposes, it is standard to transfer at a sample rate of 96 kHz and a bit depth of 24 bits per channel.[63] Challenges Many libraries, archives, museums, and other memory institutions, struggle with catching up and staying current regarding digitization and the expectation that everything should already be online.[67][68] The time spent planning, doing the work, and processing the digital files along with the expense and fragility of some materials are some of the most common. Time spent Digitization is a time-consuming process, even more so when the condition or format of the analog resources requires special handling.[69] Deciding what part of a collection to digitize can sometimes take longer than digitizing it in its entirety.[70] Each digitization project is unique and workflows for one will be different from every other project that goes through the process, so time must be spent thoroughly studying and planning each one to create the best plan for the materials and the intended audience.[71] Expense Cost of equipment, staff time, metadata creation, and digital storage media make large scale digitization of collections expensive for all types of cultural institutions.[72] Ideally all institutions want their digital copies to have the best image quality so a high-quality copy can be maintained over time.[72] However, smaller institutions may not be able to afford such equipment or manpower, which limits how much material can be digitized, so archivists and librarians must know what their patrons need and prioritize digitization of those items.[73] Often the cost of time and expertise involved with describing materials and adding metadata is more than the digitization process.[74] Fragility of materials Some materials, such as brittle books, are so fragile that undergoing the process of digitization could damage them irreparably.[70][73] Despite potential damage, one reason for digitizing fragile materials is because they are so heavily used that creating a digital surrogate will help preserve the original copy long past its expected lifetime and increase access to the item.[75] Copyright Copyright is not only a problem faced by projects like Google Books, but by institutions that may need to contact private citizens or institutions mentioned in archival documents for permission to scan the items for digital collections.[72] It can be time consuming to make sure all potential copyright holders have given permission, but if copyright cannot be determined or cleared, it may be necessary to restrict even digital materials to in library use.[74][72] Solutions Institutions can make digitization more cost-effective by planning before a project begins, including outlining what they hope to accomplish and the minimum amount of equipment, time, and effort that can meet those goals.[76] If a budget needs more money to cover the cost of equipment or staff, an institution might investigate if grants are available.[76][77] Collaboration Collaborations between institutions have the potential to save money on equipment, staff, and training as individual members share their equipment, manpower, and skills rather than pay outside organizations to provide these services.[78] Collaborations with donors can build long-term support of current and future digitization projects.[79][80] Outsourcing Outsourcing can be an option if an institution does not want to invest in equipment but since most vendors require an inventory and basic metadata for materials, this is not an option for institutions hoping to digitize without processing.[80][77] Non-traditional staffing Many institutions have the option of using volunteers, student employees, or temporary employees on projects. While this saves on staffing costs, it can add costs elsewhere such as on training or having to re-scan items due to poor quality.[80][81] MPLP One way to save time and resources is by using the More Product, Less Process (MPLP) method to digitize materials while they are being processed.[82] Since GLAM (Galleries, Libraries, Archives, and Museums) institutions are already committed to preserving analog materials from special collections, digital access copies do not need to be high-resolution preservation copies, just good enough to provide access to rare materials.[83] Sometimes institutions can get by with 300 dpi JPGs rather than a 600 dpi TIFF for images, and a 300 dpi grayscale scan of a document rather than a color one at 600 dpi.[77][84] Digitizing marginalized voices Digitization can be used to highlight voices of historically marginalized peoples and add them to the greater body of knowledge. Many projects, some community archives created by members of those groups, are doing this in a way that supports the people, values their input and collaboration, and gives them a sense of ownership of the collection.[85][86] Examples of projects are Gi-gikinomaage-min and the South Asian American Digital Archive (SAADA). Gi-gikinomaage-min Gi-gikinomaage-min is Anishinaabemowin for "We are all teachers" and its main purpose is "to document the history of Native Americans in Grand Rapids, Michigan."[87] It combines new audio and video oral histories with digitized flyers, posters, and newsletters from Grand Valley State University's analog collections.[87] Although not entirely a newly digitized project, what was created also added item-level metadata to enhance context. At the start, collaboration between several university departments and the Native American population was deemed important and remained strong throughout the project.[87] SAADA The South Asian American Digital Archive (SAADA) has no physical building, is entirely digital and everything is handled by volunteers.[88] This archive was started by Michelle Caswell and Samip Mallick and collects a broad variety of materials "created by or about people residing in the United States who trace their heritage to Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka, and the many South Asian diaspora communities across the globe."[88] (Caswell, 2015, 2). The collection of digitized items includes private, government, and university held materials.[88] Black Campus Movement Collection (BCM) Kent State University began its BCM collection when it acquired the papers of African American alumnus Lafayette Tolliver, which included about 1,000 photographs that chronicled the black student experience at Kent State from 1968-1971.[86] The collection continues to add materials from the 1960s up to and including the current student body and several oral histories have been added since it debuted.[86] When digitizing the items, it was necessary to work with alumni to create descriptions for the images. This collaboration created changes in local controlled vocabularies the libraries used to create metadata for the images.[86] Mass digitization The expectation that everything should be online has led to mass digitization practices, but it is an ongoing process with obstacles that have led to alternatives.[89] As new technology makes automated scanning of materials safer for materials and decreases need for cropping and de-skewing, mass digitization should be able to increase.[89] Obstacles Digitization can be a physically slow process involving selection and preparation of collections that can take years if materials need to be compared for completeness or are vulnerable to damage.[90] Price of specialized equipment, storage costs, website maintenance, quality control, and retrieval system limitations all add to the problems of working on a large scale.[90] Successes Digitization on demand Scanning materials as users ask for them, provides copies for others to use and cuts down on repeated copying of popular items. If one part of a folder, document, or book is asked for, scanning the entire object can save time in the future by already having the material access if someone else needs the material.[89][90] Digitizing on demand can increase volume because time spent on selection and prep has been used on scanning instead.[90] Google Books From the start, Google has concentrated on text rather than images or special collections.[90] Although criticized in the past for poor image quality, selection practices, and lacking long-term preservation plans, their focus on quantity over quality has enabled Google to digitize more books than other digitizers.[89][90] Standards Digitization is not a static field and standards change with new technology, so it is up to digitization managers to stay current with new developments.[91] Although each digitization project is different, common standards in formats, metadata, quality, naming, and file storage should be used to give the best chance of interoperability and patron access.[92] As digitization is often the first step in digital preservation, questions about how to handle digital files should be addressed in institutional standards.[93] A standard for still images adapted from the Smithsonian digitization standards might include the following:[94] Still Image Digitization Standards Filename format Analog Material Type Color or B&W Resolution of Scan RGB Setting for Scan Digital File Format File Compression Metadata YYYYMMDD_CollectionID#_Image# 35 mm print Color 600 ppi 24 bit; 8 bits per color channel TIFF None Follow Local Controlled Vocabularies and LC SH and NAF YYYYMMDD_CollectionID#_Image# 35 mm slide Color 1400 ppi 24 Bit; 8 bits per color channel TIFF None Follow Local Controlled Vocabularies and LC SH and NAF YYYYMMDD_CollectionID#_Image# microform B&W 300 ppi 24 Bit TIFF None Follow Local Controlled Vocabularies and LC SH and NAF Resources to create local standards are available from the Society of American Archivists, the Smithsonian, and the Northeast Document Conservation Center.[95][94][91] Implications Cultural Heritage Concerns Digitization of community archives by indigenous and other marginalized people has led to traditional memory institutions reassessing how they digitize and handle objects in their collections that may have ties to these groups.[85] The topics they are rethinking are varied and include how items are chosen for digitization projects, what metadata to use to convey proper context to be retrievable by the groups they represent, and whether an item should be accessed by the world or just those who the groups originally intended to have access, such as elders.[96] Many navigate these concerns by collaborating with the communities they seek to represent through their digitized collections.[96] Lean philosophy The broad use of internet and the increasing popularity of lean philosophy has also increased the use and meaning of "digitizing" to describe improvements in the efficiency of organizational processes. Lean philosophy refers to the approach which considers any use of time and resources, which does not lead directly to creating a product, as waste and therefore a target for elimination. This will often involve some kind of Lean process in order to simplify process activities, with the aim of implementing new "lean and mean" processes by digitizing data and activities. Digitization can help to eliminate time waste by introducing wider access to data, or by the implementation of enterprise resource planning systems. Fiction Works of science-fiction often include the term digitize as the act of transforming people into digital signals and sending them into digital technology. When that happens, the people disappear from the real world and appear in a virtual world (as featured in the cult film Tron, the animated series Code: Lyoko, or the late 1980s live-action series Captain Power and the Soldiers of the Future). In the video game Beyond Good & Evil, the protagonist's holographic friend digitizes the player's inventory items. One Super Friends cartoon episode showed Wonder Woman and Jayna freeing the world's men (including the male super heroes) onto computer tape by the female villainess Medula.[97] See also Book scanning Digital audio Digital library Digital television Economics of digitization ENUMERATE Frame grabber Graphics tablet Newspaper digitization Optical character recognition Raster graphics Raster image Raster to vector Scannebago Vector graphics References

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2Scanning of an object or environment to collect data on its shape It has been suggested that Volumetric capture be merged into this article. (Discuss) Proposed since April 2022. Making a 3D-model of a Viking belt buckle using a hand held VIUscan 3D laser scanner. Three-dimensional (3D)computer graphics Fundamentals Modeling Scanning Rendering Printing Primary uses 3D models Computer-aided design Graphic design Video games Visual effects Visualization Virtual engineering Virtual reality Virtual cinematography Related topics Computer-generated imagery (CGI) Animation computer skeletal 3D display Wire-frame model Texture mapping Motion capture Crowd simulation Global illumination Volume rendering vte 3D scanning is the process of analyzing a real-world object or environment to collect data on its shape and possibly its appearance (e.g. color). The collected data can then be used to construct digital 3D models. 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 dark, shiny, reflective or transparent objects. For example, industrial computed tomography scanning, structured-light 3D scanners, LiDAR and Time Of Flight 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,[1] motion capture,[2][3] gesture recognition,[4] robotic mapping,[5] industrial design, orthotics and prosthetics,[6] reverse engineering and prototyping, quality control/inspection and the digitization of cultural artifacts.[7] Functionality The purpose of a 3D scanner is usually to create a 3D model. This 3D model consists of a polygon mesh or 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 or textures on the surface of the subject can also be determined. 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. In some situations, a single scan will not produce a complete model of the subject. Multiple scans, from different directions are usually helpful 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.[8][9][10][11][12] Technology There are a variety of technologies for digitally acquiring the shape of a 3D object. The techniques work with most or all sensor types including optical, acoustic, laser scanning,[13] radar, thermal,[14] and seismic.[15][16] A well established classification[17] 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. Contact A Coordinate Measuring Machine (CMM) with scanning head. 3D scanning of a fin whale skeleton in the Natural History Museum of Slovenia (August 2013) Contact 3D scanners work by physically probing (touching) the part and recording the position of the sensor as the probe moves around the part. There are two main types of contact 3D scanners: Coordinate measuring machines (CMMs) which traditionally have 3 perpendicular moving axis with a touch probe mounted on the Z axis. As the touch probe moves around the part, sensors on each axis record the position to generate XYZ coordinates. Modern CMMs are 5 axis systems, with the two extra axes provided by pivoting sensor heads. CMMs are the most accurate form of 3D measurement achieving micron precision. The greatest advantage of a CMM after accuracy is that it can be run in autonomous (CNC) mode or as a manual probing system. The disadvantage of CMMs is that their upfront cost and the technical knowledge required to operate them. Articulated Arms which generally have multiple segments with polar sensors on each joint. As per the CMM, as the articulated arm moves around the part sensors record their position and the location of the end of the arm is calculated using complex math and the wrist rotation angle and hinge angle of each joint. While not usually as accurate as CMMs, articulated arms still achieve high accuracy and are cheaper and slightly easier to use. They do not usually have CNC options. Both modern CMMs and Articulated Arms can also be fitted with non-contact laser scanners instead of touch probes. 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. Time-of-flight This lidar scanner may be used to scan buildings, rock formations, etc., to produce a 3D model. The lidar can aim its laser beam in a wide range: its head rotates horizontally, a mirror flips vertically. The laser beam is used to measure the distance to the first object on its path. 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 {\displaystyle 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 {\displaystyle t} is the round-trip time, then distance is equal to c · t / 2 {\displaystyle \textstyle c\!\cdot \!t/2} . The accuracy of a time-of-flight 3D laser scanner depends on how precisely we can measure the t {\displaystyle 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.[18] Triangulation Principle of a laser triangulation sensor. Two object positions are shown. 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 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.[19] 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.[20] Strengths and weaknesses 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 micrometers. 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[21] and distortions due to motion and/or rotation.[22] Short-range laser scanners can't usually encompass a depth of field more than 1 meter.[23] 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. Conoscopic holography In a conoscopic system, a laser beam is projected onto the surface and then the immediate reflection along the same ray-path are put through a conoscopic crystal and projected onto a CCD. The result is a diffraction pattern, that can be frequency analyzed to determine the distance to the measured surface. The main advantage with conoscopic holography is that only a single ray-path is needed for measuring, thus giving an opportunity to measure for instance the depth of a finely drilled hole.[24] Hand-held laser 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)[25][26] 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.[27] 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 colors — to build (or "reverse engineer") a full 3D model. Structured light Main article: Structured-light 3D scanner 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.[24] [See Morano, R., et al. "Structured Light Using Pseudorandom Codes," IEEE Transactions on Pattern Analysis and Machine Intelligence. 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. 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.[28] 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.[29] By utilising the binary defocusing technique, speed breakthroughs have been made that could reach hundreds [30] to thousands of frames per second.[31] 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. Volumetric techniques Medical Computed tomography (CT) is a medical imaging method which generates a three-dimensional image of the inside of an object from a large series of two-dimensional X-ray images, similarly magnetic resonance imaging is another medical imaging technique that provides much greater contrast between the different soft tissues of the body than computed tomography (CT) does, making it especially useful in neurological (brain), musculoskeletal, cardiovascular, and oncological (cancer) imaging. These techniques produce a discrete 3D volumetric representation that can be directly visualised, manipulated or converted to traditional 3D surface by mean of isosurface extraction algorithms. Industrial Although most common in medicine, industrial computed tomography, microtomography and MRI are also used in other fields for acquiring a digital representation of an object and its interior, such as non destructive materials testing, reverse engineering, or studying biological and paleontological specimens. 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[1]. 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) cannot be detected. Photogrammetric non-contact passive methods This section needs expansion. You can help by adding to it. (March 2020) Main article: Photogrammetry Images taken from multiple perspectives such as a fixed camera array can be taken of a subject for a photogrammetric reconstruction pipeline to generate a 3D mesh or point cloud. Photogrammetry provides reliable information about 3D shapes of physical objects based on analysis of photographic images. The resulting 3D data is typically provided as a 3D point cloud, 3D mesh or 3D points.[32] Modern photogrammetry software applications automatically analyze a large number of digital images for 3D reconstruction, however manual interaction may be required if the software cannot automatically determine the 3D positions of the camera in the images which is an essential step in the reconstruction pipeline. Various software packages are available including PhotoModeler, Geodetic Systems, Autodesk ReCap, RealityCapture and Agisoft Metashape (see comparison of photogrammetry software). Close range photogrammetry typically uses a handheld camera such as a DSLR with a fixed focal length lens to capture images of objects for 3D reconstruction.[33] Subjects include smaller objects such as a building facade, vehicles, sculptures, rocks, and shoes. Camera Arrays can be used to generate 3D point clouds or meshes of live objects such as people or pets by synchronizing multiple cameras to photograph a subject from multiple perspectives at the same time for 3D object reconstruction.[34] Wide angle photogrammetry can be used to capture the interior of buildings or enclosed spaces using a wide angle lens camera such as a 360 camera. Aerial photogrammetry uses aerial images acquired by satellite, commercial aircraft or UAV drone to collect images of buildings, structures and terrain for 3D reconstruction into a point cloud or mesh. Acquisition from acquired sensor data Semi-automatic building extraction from lidar data and high-resolution images is also a possibility. Again, this approach allows modelling without physically moving towards the location or object.[35] From airborne lidar data, digital surface model (DSM) can be generated and then the objects higher than the ground are automatically detected from the DSM. Based on general knowledge about buildings, geometric characteristics such as size, height and shape information are then used to separate the buildings from other objects. The extracted building outlines are then simplified using an orthogonal algorithm to obtain better cartographic quality. Watershed analysis can be conducted to extract the ridgelines of building roofs. The ridgelines as well as slope information are used to classify the buildings per type. The buildings are then reconstructed using three parametric building models (flat, gabled, hipped).[36] Acquisition from on-site sensors Lidar and other terrestrial laser scanning technology[37] offers the fastest, automated way to collect height or distance information. lidar or laser for height measurement of buildings is becoming very promising.[38] Commercial applications of both airborne lidar and ground laser scanning technology have proven to be fast and accurate methods for building height extraction. The building extraction task is needed to determine building locations, ground elevation, orientations, building size, rooftop heights, etc. Most buildings are described to sufficient details in terms of general polyhedra, i.e., their boundaries can be represented by a set of planar surfaces and straight lines. Further processing such as expressing building footprints as polygons is used for data storing in GIS databases. Using laser scans and images taken from ground level and a bird's-eye perspective, Fruh and Zakhor present an approach to automatically create textured 3D city models. This approach involves registering and merging the detailed facade models with a complementary airborne model. The airborne modeling process generates a half-meter resolution model with a bird's-eye view of the entire area, containing terrain profile and building tops. Ground-based modeling process results in a detailed model of the building facades. Using the DSM obtained from airborne laser scans, they localize the acquisition vehicle and register the ground-based facades to the airborne model by means of Monte Carlo localization (MCL). Finally, the two models are merged with different resolutions to obtain a 3D model. Using an airborne laser altimeter, Haala, Brenner and Anders combined height data with the existing ground plans of buildings. The ground plans of buildings had already been acquired either in analog form by maps and plans or digitally in a 2D GIS. The project was done in order to enable an automatic data capture by the integration of these different types of information. Afterwards virtual reality city models are generated in the project by texture processing, e.g. by mapping of terrestrial images. The project demonstrated the feasibility of rapid acquisition of 3D urban GIS. Ground plans proved are another very important source of information for 3D building reconstruction. Compared to results of automatic procedures, these ground plans proved more reliable since they contain aggregated information which has been made explicit by human interpretation. For this reason, ground plans, can considerably reduce costs in a reconstruction project. An example of existing ground plan data usable in building reconstruction is the Digital Cadastral map, which provides information on the distribution of property, including the borders of all agricultural areas and the ground plans of existing buildings. Additionally information as street names and the usage of buildings (e.g. garage, residential building, office block, industrial building, church) is provided in the form of text symbols. At the moment the Digital Cadastral map is built up as a database covering an area, mainly composed by digitizing preexisting maps or plans. Cost Terrestrial laser scan devices (pulse or phase devices) + processing software generally start at a price of €150,000. Some less precise devices (as the Trimble VX) cost around €75,000. Terrestrial lidar systems cost around €300,000. Systems using regular still cameras mounted on RC helicopters (Photogrammetry) are also possible, and cost around €25,000. Systems that use still cameras with balloons are even cheaper (around €2,500), but require additional manual processing. As the manual processing takes around 1 month of labor for every day of taking pictures, this is still an expensive solution in the long run. Obtaining satellite images is also an expensive endeavor. High resolution stereo images (0.5 m resolution) cost around €11,000. Image satellites include Quikbird, Ikonos. High resolution monoscopic images cost around €5,500. Somewhat lower resolution images (e.g. from the CORONA satellite; with a 2 m resolution) cost around €1,000 per 2 images. Note that Google Earth images are too low in resolution to make an accurate 3D model.[39] Reconstruction Main article: 3D reconstruction From point clouds The point clouds produced by 3D scanners and 3D imaging can be used directly for measurement and visualisation in the architecture and construction world. 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. 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. 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 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 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, DezignWorks 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). From a set of 2D slices 3D reconstruction of the brain and eyeballs from CT scanned DICOM images. In this image, areas with the density of bone or air were made transparent, and the slices stacked up in 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. A black box encloses the slices to provide the black background. Since these are simply 2D images stacked up, 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 colours 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. 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,[40] enabling stress calculation throughout in excess of 2000 wafers per hour.[41] 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. From photographs 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.[42][43] This software has now been replaced by Vexcel GeoSynth.[44] Another similar software program is Microsoft Photosynth.[45][46] A semi-automatic method for acquiring 3D topologically structured data from 2D aerial stereo images has been presented by Sisi Zlatanova.[47] 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,[48] RealityCapture,[49] and ENSAIS Engineering College TIPHON (Traitement d'Image et PHOtogrammétrie Numérique).[50] A method 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 methods[51][52] Multiple images are used in Zeng's 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.[53] New measurement techniques are also employed to obtain measurements of 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] Applications Space experiments 3D scanning technology has been used to scan space rocks for the European Space Agency.[54][55] Construction industry and civil engineering Robotic control: e.g. a laser scanner may function as the "eye" of a robot.[56][57] As-built drawings of bridges, industrial plants, and monuments Documentation of historical sites[58] Site modelling and lay outing Quality control Quantity surveys Payload monitoring [59] Freeway 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, vessel/truck impact or fire. Create GIS (geographic information system) maps[60] and geomatics. Subsurface laser scanning in mines and karst voids.[61] Forensic documentation[62] Design process 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. Entertainment 3D scanners are used by the entertainment industry to create digital 3D models for movies, video games and leisure purposes.[63] 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 photography 3D selfie in 1:20 scale printed by Shapeways using gypsum-based printing, created by Madurodam miniature park from 2D pictures taken at its Fantasitron photo booth. Fantasitron 3D photo booth at Madurodam 3D scanners are evolving for the use of cameras to represent 3D objects in an accurate manner.[64] 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[65] Law enforcement 3D laser scanning is used by the law enforcement agencies around the world. 3D models are used for on-site documentation of:[66] Crime scenes Bullet trajectories Bloodstain pattern analysis Accident reconstruction Bombings Plane crashes, and more Reverse engineering Reverse engineering of a mechanical component requires a precise digital model of the objects to be reproduced. Rather than a set of points a precise digital model can be represented by a polygon mesh, a set of flat 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. Real estate 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.[67] There is already at least one company providing 3D-scanned virtual real estate tours.[68] A typical virtual tour Archived 2017-04-27 at the Wayback Machine would consist of dollhouse view,[69] inside view, as well as a floor plan. Virtual/remote tourism The environment at 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.[70] A group of history students at Vancouver iTech Preparatory Middle School created a Virtual Museum by 3D Scanning more than 100 artifacts.[71] Cultural heritage There have been many research projects undertaken via the scanning of historical sites and artifacts both for documentation and analysis purposes.[72] 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.[73] 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[74][75][76] Michelangelo In 1999, two different research groups started scanning Michelangelo's statues. Stanford University with a group led by Marc Levoy[77] used a custom laser triangulation scanner built by Cyberware 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 colour details. The digital model, result of the Stanford scanning campaign, was thoroughly used in the 2004 subsequent restoration of the statue.[78] Monticello In 2002, David Luebke, et al. scanned Thomas Jefferson's Monticello.[79] A commercial time of flight laser scanner, the DeltaSphere 3000, was used. The scanner data was later combined with colour 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. Cuneiform tablets The first 3D models of cuneiform tablets were acquired in Germany in 2000.[80] In 2003 the so-called Digital Hammurabi project acquired cuneiform tablets with a laser triangulation scanner using a regular grid pattern having a resolution of 0.025 mm (0.00098 in).[81] 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 cuneiform characters from 3D-models.[82] It was used to process ca. 2.000 3D-digitized tablets of the Hilprecht Collection in Jena to create an Open Access benchmark dataset[83] and an annotated collection[84] of 3D-models of tablets freely available under CC BY licenses.[85] Kasubi Tombs 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.[86] "Plastico di Roma antica" In 2005, Gabriele Guidi, et al. scanned the "Plastico di Roma antica",[87] 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. Other projects 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.[88] 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. Medical CAD/CAM 3D scanners are used to capture the 3D shape of a patient in orthotics and dentistry. It gradually supplants tedious plaster cast. CAD/CAM software are then used to design and manufacture the orthosis, prosthesis 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[89][90] and cadaver models for educational neurosurgical simulations.[91] Quality assurance and industrial metrology The digitalisation of real-world objects is of vital importance in various application domains. This method is especially applied in industrial quality assurance to measure the geometric dimension accuracy. Industrial processes such as assembly are complex, highly automated and typically based on CAD (computer-aided design) data. The problem is that the same degree of automation is also required for quality assurance. It is, for example, a very complex task to assemble a modern car, since it consists of many parts that must fit together at the very end of the production line. The optimal performance of this process is guaranteed by quality assurance systems. Especially the geometry of the metal parts must be checked in order to assure that they have the correct dimensions, fit together and finally work reliably. Within highly automated processes, the resulting geometric measures are transferred to machines that manufacture the desired objects. Due to mechanical uncertainties and abrasions, the result may differ from its digital nominal. In order to automatically capture and evaluate these deviations, the manufactured part must be digitised as well. For this purpose, 3D scanners are applied to generate point samples from the object's surface which are finally compared against the nominal data.[92] 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.[93] [94] Circumvention of shipping costs and international import/export tariffs 3D scanning can be used in conjunction with 3D printing technology to virtually teleport certain object across distances without the need of shipping them and in some cases incurring import/export tariffs. For example, a plastic object can be 3D-scanned in the United States, the files can be sent off to a 3D-printing facility over in Germany where the object is replicated, effectively teleporting the object across the globe. In the future, as 3D scanning and 3D printing technologies become more and more prevalent, governments around the world will need to reconsider and rewrite trade agreements and international laws. Object reconstruction Main article: 3D reconstruction See also: 3D reconstruction from multiple images After the data has been collected, the acquired (and sometimes already processed) data from images or sensors needs to be reconstructed. This may be done in the same program or in some cases, the 3D data needs to be exported and imported into another program for further refining, and/or to add additional data. Such additional data could be gps-location data, ... Also, after the reconstruction, the data might be directly implemented into a local (GIS) map[95][96] or a worldwide map such as Google Earth. Software Several software packages are used in which the acquired (and sometimes already processed) data from images or sensors is imported. Notable software packages include:[97] Qlone 3DF Zephyr Canoma Leica Photogrammetry Suite MeshLab MountainsMap SEM (microscopy applications only) PhotoModeler SketchUp tomviz See also 3D computer graphics software 3D printing 3D reconstruction 3D selfie Angle-sensitive pixel Depth map Digitization Epipolar geometry Full body scanner Image reconstruction Light-field camera Photogrammetry Range imaging Remote sensing Structured-light 3D scanner Thingiverse

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