LASER BEAM USED IN DENTAL SCANNING FOR CAD/CAM TECHNOLOGIES

Cosmin Sinescu[1], Meda Negrutiu[1], Dorin Dodenciu[2], Dalibor Cozarov[4], Mihai Rominu[1], Cosmin Balabuc[3]

REZUMAT

Tehnologia prototipării rapide intră din ce în ce mai mult în mediul tehnologic al medicinei dentare, permițând realizarea unor structuri dentare complexe într-un interval de timp redus față de toate tehnologiile existente la ora actuală. Un aspect important în această direcție este timpul scanării și al modelării viitoarei structuri dentare cu accent atât pe sistemul de scanare, cât și pe softul de post procesare utilizat. Lucrarea de față descrie sistemele performante în domeniul menționat și analizează din perspectiva prototipării rapide sistemele și softurile cele mai performante.
Cuvinte cheie: tehnologia prototipării rapide, scanare, modelare, soft de postprocesare

ABSTRACT

Today, rapid prototyping technology represents a large part of the dental technology department, offering the possibility to develop complex dental structures in a shorter period of time comparing with all the dental technologies used till now. A major aspect of this idea is the scanning and the modeling procedures of the future dental structure, concerning both the scanning device and the post processing software used for this technology. This paper describes the best scanning systems in this domain and analyzes the post-processing software used for the rapid prototyping procedures.
Key Words: rapid prototyping technology, scanning, modeling, post-processing software

OBJECTIVES

The main question of this paper is: do we need to scan? And if the answer is yes, why? The objectives of scanning in dentistry are: to establish a viable method of digitally representing dental structures,to propose a suitable scanner and post-processing software for different scanning procedures, to obtain 3D models for dentals prostheses, and to build a strong platform for future dental research groups.[1,2] All the virtual models obtained by scanning are used especially for the CAD/CAM procedures but also for exhibiting, research, and archival reasons.[3].

[1] Dental Materials and Dental Technology Department, [2] Bioinformatics Department, [3] Oral Rehabilitation Department, Faculty of Dentistry, Victor Babes University of Medicine and Pharmacy, Timisoara, [4] Dali's Dentech Dental Labor, Timisoara

Correspondence to:
Cosmin Sinescu, 1 Iuliu Maniu Str., Ap. 1, Timisoara, Tel. +40722280132
Email: minosinescu@yahoo.com

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Rapid prototyping is the name given to a host of related technologies that are used to fabricate physical objects directly from CAD data sources. These methods are unique in that they add and bond materials in layers to form objects or parts.[4] Such systems are also known by the general names three-dimensional printing, solid freeform fabrication and layered manufacturing. They offer advantages in many applications compared to classical subtractive fabrication methods such as milling or turning. These advantages are: objects can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly; objects can be made from multiple materials, or as composites, or materials can even be varied in a controlled fashion at any location in an object; the fabrication of complex objects is reduced to a manageable, straightforward, and relatively fast process. These properties have resulted in their wide use as a way to reduce time to market in manufacturing. Today's systems are heavily used by engineers to better understand and communicate their product designs as well as to make rapid tooling to manufacture those products. Dentists, architects, artists and individuals from many other disciplines also routinely use the technology in which the main goal is the scanning and modeling procedures. In the literature review, developments in the field of 3D digitization were achieved in reverse engineering (automotive, aerospace industry), medical application (reconstructive surgery: dental & orthopedic), art & archaeological (several museums collaborate with universities and research organizations to explore the field of digitization - Canadian museum of civilization and the Dongguk – display their electronic models over the internet along with a 3D virtual museum).

The cuneiform tablets are documents written on stone. Subodh Kumar and team at the John Hopkins University managed to obtain 3D models accurate to 0.025 mm for research and archival purposes in 2003. In 1999, a team from Stanford University digitized a statue of Michelangelo's David using a custom-built laser scanner to an accuracy of 0.25 mm. The total amount of information representing 32 GB of data took them five months.

MATERIAL AND METHODS

The scanning procedure is done by using the scanner devices. Scanners are the medium of data capture. 3D scanners aim to measure and record the relative distance between the object's surface and a known point in space. This geometric data is represented in the form of point cloud data. The scanner classification currently accepted divides them into contact scanning devices and non contact scanning devices.

The contact scanning devices uses a touch probe to record the relative position of points on the objects' surface. They are commonly used in reverse engineering applications. The main merits of this kind of scanners are: inexpensive and efficient for objects with low geometric surface detail. The demerits are: time consuming and impractical for artifact digitization.

The used apparatus for scanning is called **MODELA** and can scan through contact, step by step, the shape of a solid object. The sum of identified solid spots is mathematical processed and transformed into a 3D virtual image. (Fig. 1.) Before scanning, we have to attach the sensorial unit and the head for scanning. The sensor's force is a few tens grams, and can not scan objects which are modifying theirs shape at the touch of the sensor. The error can be of maximum 0.5mm and it depends by the object's shape. The maximum scanned area is 150mm on OY direction, 100mm on OX and 60mm on OZ direction (maximum height). The soft used for this scanning is called Dr. PICZA and permit the partial shift of scanning steps. The scanning system has the elements presented in Figure 1.

Figure 1. The scanning system.

Figure 2 presents the scanning of a probe. After making all measurements with special devices, the files are saved with *.igs extension (this document is recognized by all the 3D CAD systems).

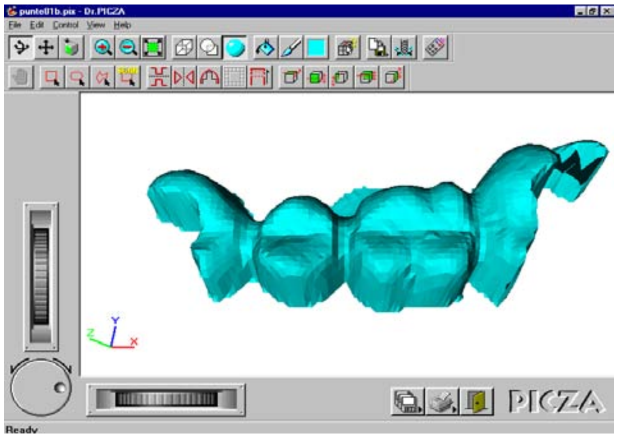

Figure 2. Aspect during the scanning process.

In the second stage, all files are imported in programs for reconstruction- 3D shaping of CAD type as PROENGINEER files. If the surface is continuous, the "Wire-frame" representation is in just one color. All the discontinuous surfaces are marked with yellow. For 3D shaping a continuous surface is necessary. The import of *.igs file in PROENGINEERING maintains the three plans which define the system's coordinates and the taken measurements. You can correct the surface in PROENGINEER with program's specific tools, or adding new surfaces compatible with the surface's measured geometry.

Next, the plane surface that passes at the bottom of the cast and is involved in volume defined will be made. The cross surfaces are delimitated between the measured surface of the partial fix prosthesis and the plane surface. This can be done with "MERGE" command, that removes the auxiliary surfaces and a 3D continuous surface (the expression is "QUILT")is born. After performing the "QUILT" the solid is made with "CREATE SOLID- USE QUILT". A solid 3D body with specific characteristics which depends on the material is obtained; with it's help, numeric simulations of forces at impact can be done. (Fig. 3)

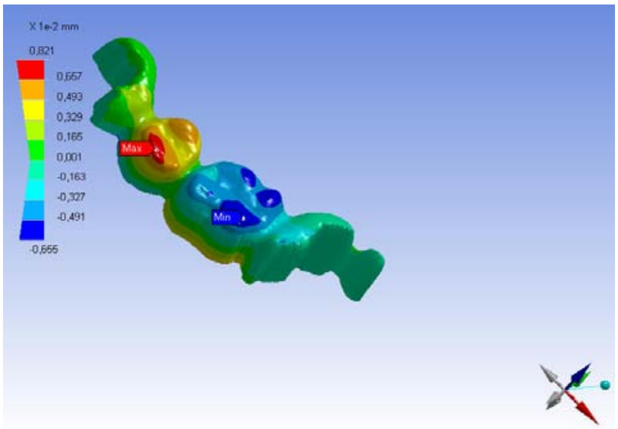

Figure 3. The results of the numerical simulation.

Non contact scanning procedures consists in laser scanning and photogrammetry. The main feature for this technology is the laser triangulation. This procedure implies: laser beam directed on to the dental artifact, the position of the reflected beam is sensed by CCD (Charged Coupled Device), the distance information is related to the position of the laser dot on the sensor, and the triangulation components, laser emitter, object and sensor, form a triangle.

Polhemus FastSCAN, Cobra Laser Scanner has a laser power of 1 mW, the acquisition rate is 15000 points per second, the point accuracy is 1 mm (at 200 mm), the point to point distance is 0.5 mm (at 200 mm), the working range reaches 750 mm (0.75 m). This device could not capture the color of the dental artifacts.

For the **Polhemus FastSCAN, Scorpion Laser Scanner,** laser triangulation technique are realied with two sensors. This scanner uses a magnetic field to localize the position of the scanner head. The devices is portable, light-weight. This device was used by Weta Workshop – to create 3D Models for 'Lord of the Rings' movies. The limitations of this system are the accuracy (± 1 mm), cannot capture color information and has poor performance with metallic, dark and reflective surfaces. The handheld laser scanner can be used to digitize a human shape for animation, multimedia, custom apparel design, biomedical research, forensics, etc. The following examples demonstrates the scanner's ability: scans a human subject rapidly while the subject remains still, uses the second receiver on a headband to track involuntary movement of the subject, scans a complicated surface with convolutions that would normally be obscured from a conventional turntable-based laser scanner, digitizes the surface of objects for animation, rapid prototyping, 3D measurement, and archiving, rapidly digitizes the complete 3D surface of an object, and saves the data in industry standard formats to be used by other programs.

Micrometric Vision Technologies Scanner (MVT) present a real time acquisition of color and point cloud data. The unit can be attached with the Microscribe contact scanner (at CACM) being the most cost effective solution for scanning small artifacts. The accuracy is 0.1 mm for this device that is also light-weight, portable, versatile and easy to use. Arius3D - Foundation System 3D Scanner (Arius 3D) creates perfect digital copies of real world objects. This astounding technology allows the user to capture, in almost microscopic detail, the shape of an object, as well as exposing the pigment of its surface, independent of ambient light. Arius3D seamlessly integrates into any organization to deliver useful scientific data that can be scaled and repurposed almost at will, with the utmost simplicity. As specifications it can be mentioned the minimum resolution, X and Y axes 250 dpi, the minimum resolution, Z axis 25 microns and the speed is 3000 points per second. The Foundation System consists of a laser scanner and a motion control system for moving the scanner. The shape measurements are completely independent of the effects of ambient light. Scanned data are recorded and processed by software to transform the data into high-quality, 3D color images. The laser scanning mechanism characterizes each point on the scanned object according to its color and location in 3D space. It does this by scanning the surface of an object with three different laser wavelengths (red, green and blue) in one focused beam, and recording the reflected light.

Each point on the object is described by 6 numeric values; positional values X, Y, and Z, and surface color values R, G, and B. X-axis: Scanning in the X direction is accomplished by a galvanometer-driven double-sided mirror. The position of each point on the X-axis is developed from the known angular position of the mirror. Y-axis: Scanning in the Y direction is accomplished by motion perpendicular to both the laser axis and the X-axis, usually implemented as a translation stage. The position of each point on the

Y-axis is developed from the known position of the stage. Z-axis: The position along the Z-axis is measured by laser triangulation, enhanced by the application of synchronized scanning geometry. This patented method uses one side of the galvanometer-driven mirror to deflect the laser across the scanned object while the opposite side of the same mirror is used to cancel the return beam's angular movement across the CCD sensor. With this geometry, only a change in the position of the light spot along the Z-axis produces net movement across the CCD sensor. A patented sub-pixel interpolation scheme is used to enhance the resolution of the CCD sensor.

Scanning times are quite variable, depending on the scientific objectives of the researcher, the geometrical and material characteristics of the objects being scanned, and the scanning system in use. In general, if the details being inspected are large in proportion to the overall object (low frequency geometry), scan times are shorter; conversely, if the features being studied are small in proportion to the overall object (high frequency geometry), longer scan times will be required to distinguish them with sufficient clarity.

The **Konica Minolta Scanner – VIVID 9i** is the laser triangulation system to capture color and texture. The scans need to be manually merged unless the supplied rotating table is used. The system is unable to capture regions with undercuts and it is ideal for medium (36 cm x 27cm) to large objects (90 cm x 120 cm). The VIVID 9i is based on the principle of laser triangulation. A target is scanned with laser stripes. The CCD camera receives the light reflected from the surface of the subject. Surface shape measurements of the subject are obtained through triangulation, and converted into a 3D polygon mesh. The VIVID 9i measures 640 x 480 points with one scan, simultaneously acquiring surface shape data and color image data. The VIVID 9i can be combined with PSC-1 , Konica Minolta's optional photogrammetry system. The combination of the VIVID 9i and PSC-1 provides for fast and accurate measurement and data assembly even for relatively large targets. It is also effective to correctly align surfaces having no characteristic shape, such as projections and depressions.

The **Faro - Laser Scanner LS Range**. The FARO Laser Scanner LS is a portable non-contact measurement system that uses laser technology accurately to measure manufacturing plants, processing facilities, and in specialized applications ranging from forensics to heritage sites. The system rotates 360 degrees and automatically measures everything within the line of sight from the scanner's position. The stand-alone system records millions of 3D measurements in real time. Designed with user friendliness in mind, the high performance of the scanner can be used with minimal training to capture 3D point cloud data. The FARO Laser Scanner LS works by sending an infrared beam into the centre of a rotating mirror. This deflects the laser on a vertical rotation around the environment being scanned, the beam is then reflected back into the scanner and the "Phase Shift" of the infrared is measured giving the distance of the laser from the object. Using encoders to measure the mirror rotation and the horizontal rotation of the Laser Scanner, the X,Y,Z coordinates of each point can be calculated. Once a scan has been performed, the user can easily navigate a 3D view where the entire scan data can be inspected and analyzed. The on-board PC enables the scanner to be operated without the use of a laptop. To measure distance FARO's Laser Scanner LS uses "Phase Shift" technology as opposed to "time of flight" distance recording. This means that instead of a single pulse being reflected and the time of flight being measured, constant waves of varying length are projected. Upon contact with an object, they are reflected back to the scanner. The distance from the scanner to the object is accurately measured by measuring the phase shifts in the waves of infrared light. The Laser Scanner LS splits the laser beam into three component parts operating on three different modulation lengths 76 m, 9.6 m and 1.2 m, as shown in the wave modulation diagram on the next page. The distance of the reflecting object from the scanner is determined by identifying the location of the reflection in the 1.2 m cycle.

First, the cycle the reflection occurred has to be identified, as the beginning of each cycle will begin the distance reading again. A distance of 2 m measured only on the 1.2 m modulation would only read as 0.8 m as the measurement was in the second cycle but there is no longer modulation length to indicate this. This is known as inambiguity. For example, a reflection from 13 meters will register within the 76 m range as shown by the light green area on the diagram. This is within the second cycle of the 9.6 m range as shown in light red, and the accuracy is achieved by measuring in the 2nd cycle of the 1.2 m range after the beginning of the second cycle of the 9.6 m range. Due to the 76 m modulation length the FARO Laser Scanner LS is capable of measuring up to 76 m without inambiguity. Points measured beyond 76 m may be pushed back by the user through the software command. The main advantage of the phase shift technology is the speed of point capture, 120,000 points per second, compared to approximately 4,000 points per second for traditional "time of flight based scanners". The use of three varied ranges means a higher degree of accuracy can be achieved over a greater distance, as the specific range of the target is measured with a resolution of 17 bit or 0.58 mm. The scanner consists of four interchangeable component parts. The laser module, the mirror module, PC module and base module. These modules can be exchanged and upgraded by the user giving a flexible solution for all applications.

The scanner is capable of recognizing the shade of the reflected surface. This builds a 360° point cloud with grey scale that results in a black and white image similar to a 3D photograph. The Laser Scanner LS is linked to FARO Scout software, which allows the scan settings to be adjusted (resolution, scan speed, scan storage location, user identification) or even to select a smaller area to be scanned rather than the full 360 x 320 degrees. With the click of one button the scan will begin and the captured data is displayed live on screen.

Once the scan is complete the user can navigate the scan in 2D or 3D views. In 3D the user can fly through the point cloud data taken. A quick view is also possible, which displays a spherical view from the scanners perspective giving a good overview of the data captured.

Laserdenta OpenScan. When scanning, Laserdenta's OpenScan generates millions of data points from a jaw, so your virtual model in the Dental Software represents a true high precision copy. The scanner's laser line reaches deep, so it can capture the most important information from the preparation (to recreate the optimum margin line for the Dental CAD software). It saves you time, too: to scan single dies (stump, abutment, inlay), you no longer need to cut the working model first. You can scan from the impression or solid model, whichever is the most precise copy. This five axis scanner with laser line reaches the 360 degree of the preparation and in between teeth, so it is not necessary to individually remove each stump for scanning. Laserdenta's Scanner is the only dental scanner that can scan impression, solid model, cut and trim working model or single die preparation, bite registration and implants.

The **3Shape D 200** is a state-of-the-art 3D scanner for almost all dental scanning applications. It operates on a laser plane principle using two cameras. All points on the surface (including undercuts) are captured by moving the object along three axes. The prepared model to be scanned is fixed to the scan adapter with modeling clay. For the scanning procedure, simply place the object in the scanner and push the start button: 3Shape's unique adaptive scanning technology ensures that the whole geometry of the object is accurately captured. The software automatically recognizes if certain areas have not been scanned and then re-scan missing part from a different angle. The data acquisition for an entire crown takes only 1-2 minutes. The scanner prepares the data ready for further processing in the 3Shape's Dental Designer CAD program.

To convert sections of point cloud data of artifact to a complete 3D model, a set procedure has to be followed. Procedure is the same for all post-processing software:

1. Eraser – Deleting Noise (isolated clouds of point data – background noise can be manually deleted; volumetric selection tool – to manually highlight noise using cursor; greatly reduces size of point data and is most frequently used).

2. Outlier Removal (eliminates erroneous data points with a finer tolerance, tolerance level can be manually specified by user, depending on the quality of the scans obtained; software uses inbuilt algorithms such as fit and miniball criterion, and nearest neighbor reciprocity criterion).

3. MLS Smoother (reduce or increase average variation in relative point heights; uses moving least squares algorithm based on user input).

4. Point Relaxation (aims at obtaining a point cloud with an even distribution of data; data points appear at irregular distances – affected by scanning speed and geometry of surface; reduces number of points to obtain uniform clouds of point data).

5. Surface Wrapping (after a noise free evenly distributed set of data points, surface wrapping is used to create a polygon model; polygon model: triangles are used to create a planar link; number of triangles, is specified by the user; trade-off between accuracy and polygon model's data size).

6. Filling Holes (holes appear in polygon model: due to presence of undercuts, deep crevices and surface reflectance; due to improper merging of polygons during surface wrapping phase; holes to be filled can be selected by user – by specifying the circumference; algorithms mathematically compute optimum triangle mesh needed to fill the holes; curvature based filling – for uniform surface geometry).

7. Color Mapping (color data can be applied to the polygon model – using high resolution color images; maps the color image to the model – by correlating identical points between the model and image; color mapping accuracy is proportional to number of data point pairs).

RESULTS

When assessing results depending on the scanners used, the MVT scanner is proposed as the best scanner, because of the ability to capture color data, best price, handheld, lightweight and the fact that it can be integrated with CACM's Microscribe digitizer. This device can be used for metallic objects as well. After looking on post-processing software, comparing the results from both software packages, models from Geomagic studio are more representative for the dental artifacts. Geomagic Studio is much more simple and intuitive to use, less expensive than Rapidform 2006 and catered for people with little knowledge about laser scanning technology and 3D modeling.

CONCLUSIONS

A review of digitization projects and current technologies has helped in the conception of a digitization process for our research department. The MVT scanner has been proposed due to its performance capabilities and low cost. It is also highly portable and versatile in terms of its scanning abilities. Geomagic Studio is proposed as the optimal post processing software for this project. Its ease of use and supreme rendering capabilities have made it the software of choice. Using the existing Modella and Zeno scanner, the team has been able to obtain scan data for many dental artifacts that were used for numerical simulation application or for milling technique in CAD/CAM procedure for fixed partial dentures technology.

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