THE USE OF 3D SCANNING AND RAPID PROTOTYPING IN MEDICAL ENGINEERING

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Abstract: *New cost effective scanning and modeling techniques are used today to process data acquisition and 3D reconstruction in order to fabricate prostheses and orthoses by 3D printing. Paper approaches two scanning and 3D modeling techniques used in order to fabricate orthoses and prostheses. In this study, an artificial prosthetic ear was produced through 3D printing using two scanning techniques: structured light scanning technique and single camera stereo photogrammetric scanning technique. The processing phases are described and discussed from data acquisition to 3D printing. The surface scanning and 3D reconstruction techniques will continue to increase the accessibility of prostheses and orthoses, making them more cost-effective and more comfortable.*

Key words: Structured light scanning, stereophotogrammetry, ear, 3D reconstruction, comparison

1.INTRODUCTION

The manual methods for creating customized prostheses and orthoses have many drawbacks including the intensive work, time-consuming and imprecise process which may affect the comfort of prostheses or orthoses. The use of the new computer aided technologies is often faster and decreases the amount of practitioner time required for each visit to patient.

Prostheses and orthoses manufacturing with computer aided technologies may include next main phases in connection with image processing and fabrication [1,2,3]:

- 3D Scanning;
- 3D digital model reconstruction;
- Fabrication by Rapid Prototyping.

1. Scanning

There are a lot of commercial solutions for anatomic surface scanning (excluding internal tissues). Most known are:

- Laser scanners;
- Structured light scanners;
- Scanners with video cameras and markers;
- Stereophotogrammetry.

2. 3D model reconstruction

Computer programs (known as scanning software) are used in scanning techniques to perform 3D digital construction. The main processing phases of the 3D scanning and reconstruction software are to import the photos from the scanning device, to eliminate the artifacts and to transform the data into 3D digital model.

3. Fabrication by Rapid Prototyping

CAD/CAM and Rapid Prototyping are indispensable tools for the technological improvement in the conception and manufacturing of customized prostheses and orthoses [3,4]. 3D printing is a low-cost alternative to traditional rapid prototyping for fabricating customized components. 3D printing is a process of making 3D solid components from digital models using additive techniques and creating by laying successive layers of material.

The classic manual method of prosthetic ear manufacture consists of taking the ear impression and forming the mold by using hard dental stone. A wax model is prepared in this mold and finally the prosthesis is processed with silicone. This method may discomfort the patient and underlying tissues may distort. Also, the conventional method needs experienced technician and a long time for laboratory work.

Karatas et al [6] used computerized tomography of the skull in order to prepare the auricular prosthesis. This solution uses invasive radiations that may harm the body.

Ciocca and Scotti [7] proposed the use of Rapid Prototyping technique only in an intermediate phase, in order to create a negative mold used in the definitive prosthesis fabrication. The authors developed a method to eliminate the use of conventional impressions and the necessity to depend on the artistic skills of an anaplastologist.

Liacouras et al [8] used an acquisition system consisting of 5 synchronized cameras and rapid prototyping to produce the mold for auricular prosthesis. Prosthesis fabrication and insertion that would usually require a week can now be accomplished in 1 to 2 days.

Sansoni et al [9] used a novel approach that combines a laser scanner, reverse engineering (RE) and rapid prototyping (RP) for mold production in the prosthetic reconstruction of facial prostheses. Depending on the material used for the actual prosthesis, the solutions can be used either to directly cast the final prosthesis or to fabricate the positive wax pattern.

Subburaj et al [10] proposed a procedure that involves five steps: 1. CT image data acquisition for deficient and contralateral ears; 2. reconstruction of the corresponding 3D models using medical modeling software; 3. design of the missing ear using a haptic CAD system; 4. fabrication of prosthesis master using RP system and 5. fabrication of the final prosthesis using a mold made from the master.

In this paper we propose two ear shape extraction and reconstruction strategies in order to fabricate the reconstructed 3D model with a 3D printer. Multi-view ear images are firstly obtained and reconstructed using a structured light scanner and the associated software. Secondly, a single camera stereo photogrammetric scanning technique is used in order to extract ear shape and to reconstruct the 3D model with specific software.

Proposed scanning and reconstruction for ear fabrication strategies are the most cost effective and have only three major phases compared to known procedures: scanning, 3D image processing and 3D printing. Some characteristics of these strategies are discussed.

2.METHODS

A structured light scanner was used to develop a 3D digital image of the existing ear of a patient. The image was mirrored and used to manufacture the prosthetic ear by means of a rapid prototyping machine. This procedure is time and cost effective.

These 3D scanners project patterns of light on the body using a video projector and the cameras record the distorted pattern. They usually use several pairs of cameras, with the images sent to software that calculates the binocular disparities between corresponding points in each pair of images. The 3D geometry is inferred using stereoscopy. They usually have several pairs of cameras, with the images sent to software that calculates the binocular disparities between corresponding points in each pair of images and reconstructs the 3D model.

The second scanning technique proposed in this study, the single camera photogrammetric technique uses a single camera. The technique includes software capable to calibrate cameras and to determine the position of the camera when picturing an image. This scanning method is able to digitize objects with any digital photo camera. When picturing an object, the number of required frame should be between 20 and 40 and the surfaces should be permanently in focus and lit with a diffuse illumination.

The 3DSOM scanning software used in this study compares images patch by patch to find the matches and when these matches are found, the position data of the photographs is used to assemble the patches in the 3D space, performing a 3D digital reconstruction.

Finally, the prosthetic ear is printed experimentally using the reconstructed 3D model and a cost effective 3D printer.

3.RESULTS

In the first approach, a study was performed in order to scan and to reconstruct the ear of a person using the structured light scanning technique. A commercial Artec MH scanner as in Figure 1 was used.

Figure 1. The Artec MH scanner

The Artec MH 3D scanners use video camera technology and project structured light onto the face of patient and capture a multitude of frames. Laser scanner works using a triangle between the scanner lens, laser, and object being scanned. The frames are combined automatically (in the scanner software) into a single 3D mesh, in the 3D reconstruction phase.

The mesh represents the 3D surface model of the ear. Figure 2 shows the 3D reconstructed models made with 3D laser scanner software. The outputs are *pmjx*, *ascii*, *pmh*, *obj*, and *stl* files. The *pmjx* and *ascii* files are point clouds while *obj*, *pmh*, and *stl* are triangulated point clouds.

Figure 5 shows results of 3D scanning and 3D reconstruction performed with Artec scanner and with the associated software. In the final phase, the 3D model of the ear was transferred to the software of a 3D printer, BFB 3D type (Figure 3) in order to convert the CAD model to 3D print data

Figure 2. The 3D model mesh of ear (left) and 3D shaded model (right)

The BFB 3D Touch printer has multi-material free forming capabilities, 3D printing volume of 275x275x210mm³, and 125μm layer thickness. This printer is one of the most affordable 3D printers in its category and is on the market for about 3,000 euro.

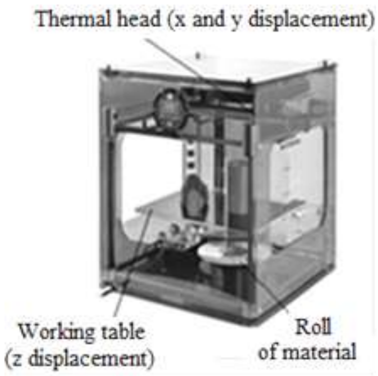

Figure 3. The 3D Printer used in ear fabrication

The printer use melting or softening material (ABS or PLA) to produce the layers of the object. Figure 4 shows the artificial ear created by the 3D printer.

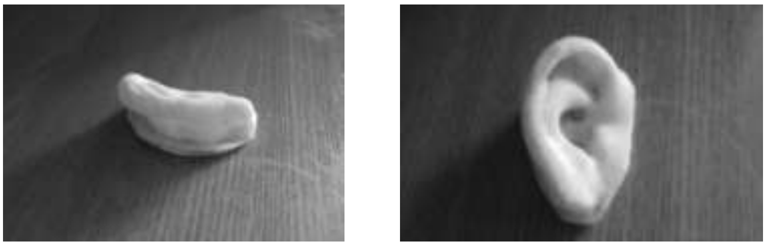

Figure 4. Pictures of the artificial ear

In the second approach, a photogrammetric scanning technique was used. It has two major advantages: it is the most cost-efficient (about ten times cheaper than laser or structured light techniques) and does not use disturbing or dangerous light (passive method). After picturing the ear using a calibration grid (Figure 5) the scanning software compares photos patch by patch and performs background elimination (Figure 6) and 3D reconstruction. After 3D reconstruction (3D mesh and 3D shaded models, Figure 7), a series of image processing by using different CAD or graphic software are necessary in order to obtain the final form of prosthesis or orthesis.

Figure 5. Picturing the ear

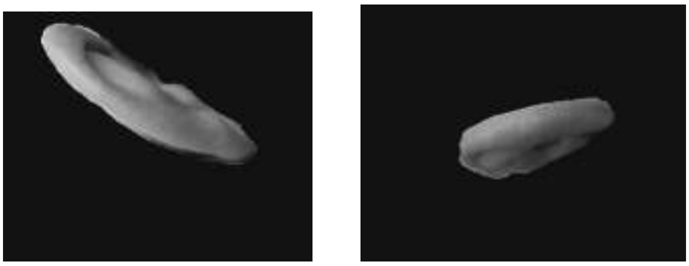

Figure 6. Elimination of the background

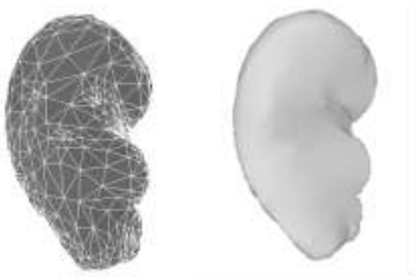

Figure 7. The 3D mesh model (left) and the shaded model of ear (right)

The 3D mesh model necessary for further processing does not contain al necessary details, mainly the anatomic indentations. In this situation, the 3D model may be processed by carving, using a supplementary CAD software. But carving anatomic details is a tedious and time consuming operation.

4. DISCUSSION

The study approached an experimental fabrication of an artificial ear made of ABS in order to compare two fabrication strategies. The first one was the use of the structured light scanning and of the 3D printing and the second strategy, the use of the photogrammetric scanning and of the 3D printing. The first solution has as principal advantage the speed of processing steps and especially the speed of 3D reconstruction phase. The second solution, of photogrammetric scanning, is the most cost-effective (about ten times cheaper than the first) but time consuming during the 3D reconstruction phase that needs supplementary software and a lot of modifications in order to reveal the indentations.

In a future approach, the 3D printing of the artificial ear should be made of a material that simulates human tissues with respect to texture, color, weight and translucency. The material should feel soft and velvety to light finger pressure. Coloring of the artificial ear requires matching the complexion of the skin wearer of the prosthesis.

Based on the results of this study, the ear should be fabricated using a stereolithography machine which employs a liquid photopolymer, the Iflex 500 from EnvisionTEC. This material is commercially available but it is expensive.

Meantime, new advanced technologies have appeared proposing lifelike artificial ear made of living cells and built using 3D printing technology [11].

5.CONCLUSIONS

The use of the new computer aided technologies is often faster and decreases the amount of practitioner time required for manufacturing of orthoses or prostheses. New scanning techniques and 3D printers are available.

Practitioners have to choose between cost effective scanning techniques (photogrammetry) and fast processing scanning techniques but more expensive (structured light scanners or laser scanners).

Results of experimental 3D scanning and 3D printing showed that fabrication of cosmetic artificial ears is actually fully feasible.

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