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Dental measurements using 3D models of plaster imprints

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Abstract- 3D technology is becoming increasingly popular and new applications emerge as well as low cost hardware to enable fast 3D rendering and processing. An emerging aspect of 3D technology is measuring real-world objects that have been digitized in the form of a 3D model. To this end, 3D scanning technology has been introduced to create 3D representations of objects with a minimal error. In this work, we present the process of digitizing a dental plaster imprint to be used in medical applications or e-learning courses. Simultaneously, the error that occurs in each 3D modeling step is presented and discussed. Then, practical 3D measurements of the object are conducted, using open-source 3D processing tools. Our goal is to create a digital repository on the Web which would facilitate dental applications and e-learning.

Keywords. 3D scanning, medical measurements

I. INTRODUCTION

Research in recent years has focused on 3D applications, such as 3DTV, 3D cinema and web3D which are becoming more and more popular. In addition, digital warehouses of user-created 3D objects are available on the web, so that large numbers of 3D models are easily distributed [1].

In accordance with this trend, the measuring of real-world objects is shifting from two dimensions to three. To this end, objects are digitized into 3D models using 3D scanning technology [2], which has recently become mature. These models can be easily shared through the web and used for measuring.

3D object modeling can be used on medical applications and teaching. This way, useful observations can be made by measuring a 3D object, taking advantage of the internet and an inexpensive computer.

This paper describes the steps that need to be followed in order to create a 3D model from a dental plaster imprint (Section II). In the same section, the error that occurs in each processing step is discussed in order to provide a safe conclusion about the practicality of 3D modeling for medical measurements. Then, this work presents some examples of the measurements that can be conducted using open source tools, such as MeshLab [3] and Blender [4] (Section III). Section IV concludes this work.

II. 3D SCANNING PROCESS

This section presents the 3D scanning steps that are required to capture the 3D representation of dental plaster imprints [5]. To this end, 10 3D models of denture imprints were created for the purposes of this section. The advantages and disadvantages of the process are also reported. For the experiments, the M300 3D scanner from Imetric was used [6].

Typically, a 3D scanner [7] is used to acquire three dimensional points of an object surface. The points could be of a large number, so they are usually called “point clouds”. To create a point cloud, the 3D scanner employs photogrammetrical techniques using two cameras, which acquire image sequences of the object from slightly different Points of View. Stereophotogrammetry estimates the depth of each object point, by correlating the pixels of the two cameras and applying triangulation. The registration/correlation of the images is facilitated by exposing the object to structured light, that is, parallel vertical and horizontal lines of white light (Figure 2). However, before acquiring an object point cloud, the cameras need to be calibrated. With the calibration process, the internal orientation parameters of the cameras are estimated, so they become "metric cameras" to be used for measurement purposes. To calibrate a camera, a reference plate is used, which includes a-priori measured reference targets. In our case, the calibration error rate reached 5-7 micrometers.

A schematic representation of a 3D scanning system is shown in Figure 1.

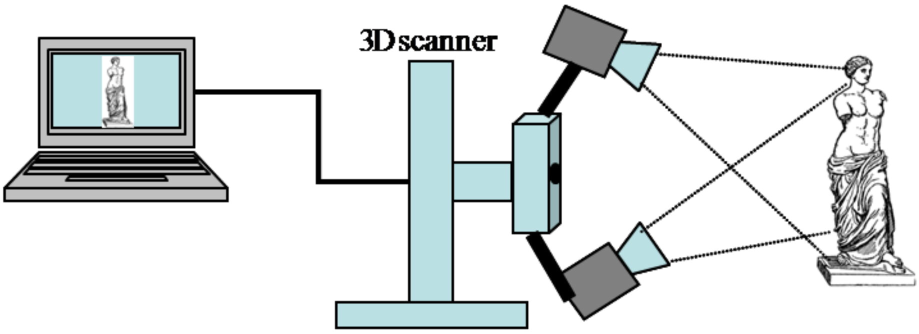

Figure 1. A 3D scanner schematic representation

Each point cloud is composed of 80.000 to 120.000 points, arranged in 3D space. This number depends on the size and the material of the scanned object as well as on the lighting conditions during scanning. More specifically, transparent or semi transparent objects cannot be digitized into a 3D object since the structured light, projected on the object, has to be visible by both cameras. So, an antiglare substance, such as chalk, has to be applied on the scanned object in order to minimize reflection and refraction. Additionally, the scanning process should be done in a controlled environment, since bright light can affect recognition of the structured light by both cameras. In our case, the plaster of the dental imprint is opaque and the scanning process is performed under mild lighting conditions, which facilitate the 3D scanning procedure.

Figure 2. Scanning a plaster dental imprint

The error rate produced by the scanner during the acquisition of a point cloud is between 10 and 20 micrometers, which can be considered insignificant. It should be noted that this error rate depends on the so called “viewing volume” of the 3D scanner, that is, the volume in which the scanner can acquire points. The viewing volume depends on the distance between the two cameras, a feature which can be adjusted. However, each time the camera distance is changed, a new camera calibration is necessary. A small viewing volume is acquired when the cameras are placed in close proximity to each other, and the smaller the distance between the cameras is, the lower error rate appears. Conversely, a larger viewing volume is captured by placing the cameras further apart, increasing in this way the error rate of the scanning process. In this study, a medium-sized volume has been chosen so that the whole scanned object is captured in one image.

Next, in order to capture the object details, several point clouds have to be created, each for a different Point of View. The point clouds derived from the process have to be aligned in 3D space, since alignment error may occur due to noise, slight movement of the object during scanning and so on. A typical method to minimize this error is to use unique markers placed near the object. In each 3D scanning iteration, the system identifies the markers and automatically aligns the point clouds. In our case, the alignment error rate never exceeded 1millimeter. To effectively capture all aspects of the dental imprint, 15 to 18 point clouds were required from different Points of View, starting from the top view and then scanning the horizontal aspects of the object. Next, the point clouds acquired are converted to triangulated meshes. Figure 3 presents in different colors how several meshes acquired from different views are aligned together.

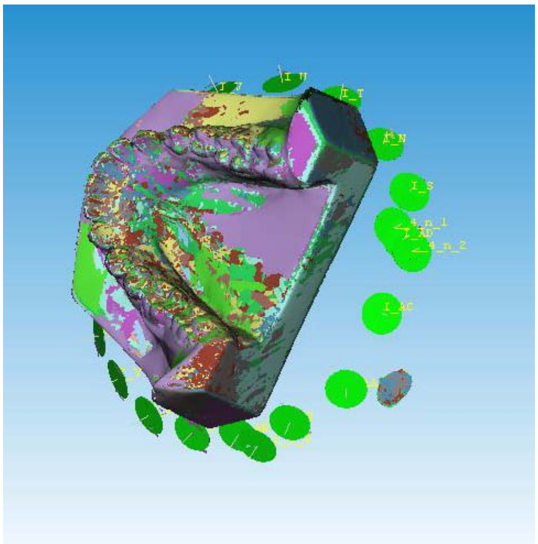

Figure 3. A 3D model derived from several scan iterations

Finally, the resulting meshes are combined to a single 3D object, which can be loaded on a 3D processing application. There are several 3D model formats that can be used to store and manage 3D objects either in a local system or on the internet. The most popular are the .3ds, used by the Autodesk 3DS Max modeling, animation and rendering software, the Wavefront object (.obj) and the COLLADA (COLLAborative Design Activity) model format.

The 3ds 3D modeling format comes in binary form. It is widely used with the Autodesk 3DS MAX software, which is a commercial application for building 3D scenes and animation. The 3ds model format is faster to load and smaller in size than human-readable ASCII-based formats. However, it is not free to use or open-source.

The .obj is a geometry definition file format developed by Wavefront Technologies. The file format is open and has been adopted by several 3D graphics application vendors, making it a universally accepted format. The .obj file is stored in an ASCII file and simple to read, providing however larger files than the .3ds format.

The COLLADA format is managed by the non-profit technology consortium, namely the Khronos Group. COLLADA defines an open standard XML schema for exchanging digital assets among various graphics software applications. COLLADA documents that describe 3D models are XML files, usually identified with a .dae (digital asset exchange) filename extension. Although it is an open source standard, it is not widely used yet and it is difficult to read. Additionally, the xml nature of the format leads to even larger files stored in the file system than the Wavefront .obj format. Nevertheless, it presents much functionality and can easily be extended, two factors which could contribute to making COLLADA the most popular format in the future.

In this work, the simpler format was chosen, the .obj. Each 3D model file is approximately 20MB in size, which can easily be distributed through a modern DSL internet connection via a 3D model repository.

III. DIGITAL MEASUREMENTS OF 3D MODELS

This section presents the digital measurements that can be conducted using open-source tools. Since the error rate introduced in the 3D scanning steps does not exceed 1mm, it is safe to say that the digital measurements in 3D are fairly accurate.

Firstly, viewing the 3D object from different angles is made easy (Figure 4) by using a simple 3D processing application.

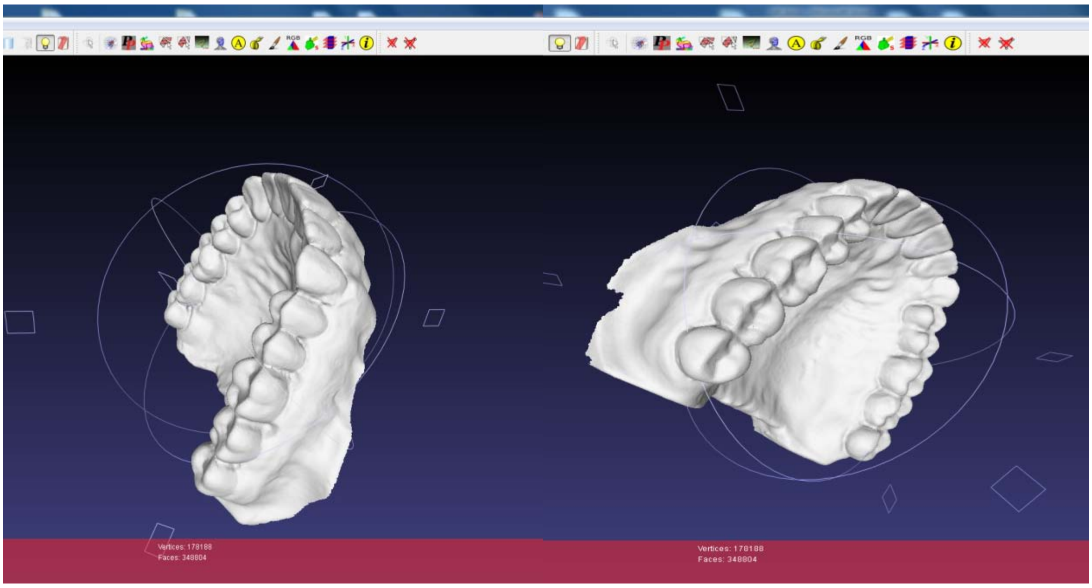

Figure 4. Viewing the 3D object from different angles

In Figure 5 the distance between two molars is measured in centimeters using the MeshLab tool.

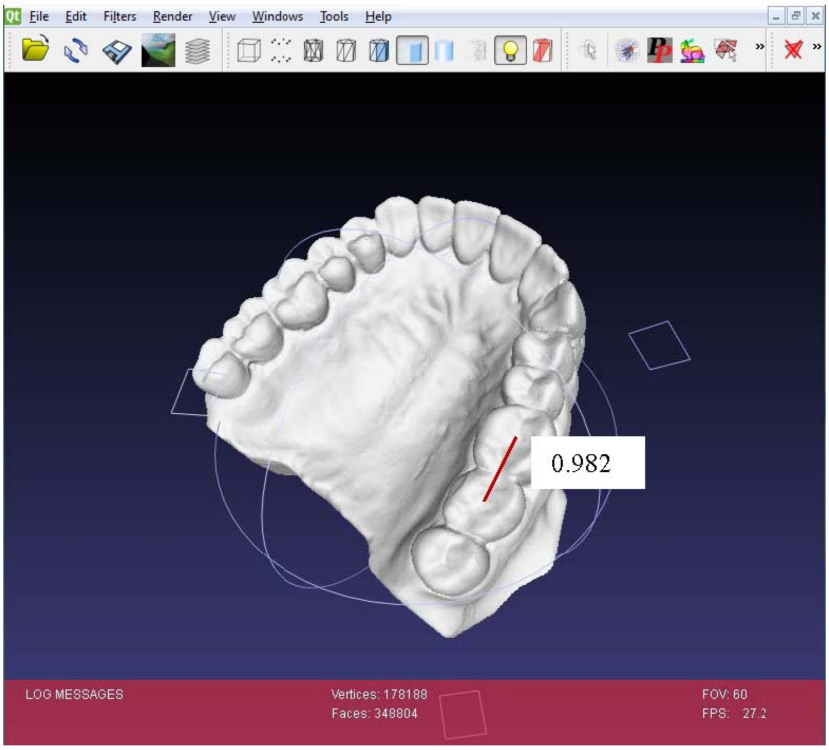

Figure 5. Measuring the distance between two molars

As a final example, in Figure 6 the arch width of the dental imprint is measured in centimeters.

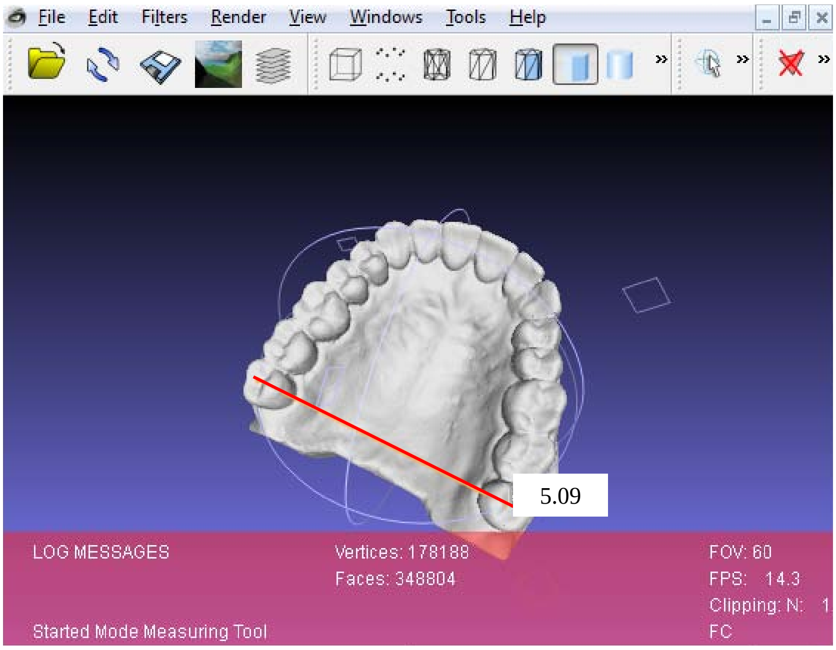

Figure 6. Arch width measurement

The above examples are presented through MeshLab, which is a very simple to use 3D processing software. Respectively, the blender tool provides the same functionality, however it is much more difficult to use.

IV. CONCLUSION

This paper presents the steps to create a 3D representation of real-world objects, that is, dental plaster imprints, using structured light 3D scanner. The error rate is presented in each step of the 3D scanning process and found to be minimal, therefore, we can safely conclude that it is possible to create accurate 3D models from the dental imprints.

The 3D objects of the plaster imprints can be used in a number of applications. These include conducting accurate virtual biomedical measurements, educating students of dentistry through blended or e-learning courses, as well as increasing accuracy and precision of pre-surgical planning.

A disadvantage of the process is that a controlled environment is required to create an error-free 3D model. A complex environment including shadows and bright lighting could render a structured-light 3D scanner ineffective. Another disadvantage is that even though the models are of a relatively small size (20MB), storing and distributing large numbers of them could be problematic. A solution to this problem would be to simplify the 3D model mesh, which, however, would lower the levels of detail. Finally, careful scanning of the objects should be conducted to eliminate holes, that is, the surfaces that the scanner cannot convert to a point cloud.

Future work includes the creation of a 3D repository on the web. This 3D database would be uploaded to a web site, or a Learning Management System (such as Moodle) to distribute the objects along with detailed instructions on how to conduct 3D measurements.

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