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DESIGN AND DEVELOPMENT OF A PROTOTYPE FOR 3D SCANNING IN BIOMEDICAL APPLICATIONS

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Abstract: In dentistry, a technique widely used for planning and/or dental procedures is molding. This consists of acquiring the negative of the molded arch in order to obtain a faithful plaster copy of the patient's oral cavity. However, this procedure causes discomfort for the patient and high costs for the dentist. There is a device on the market today that scans the jaws and replaces this conventional molding, but the cost of acquiring this equipment is still very high. In order to solve this problem, this study proposes the creation of an intraoral scanning device with efficiency and lower cost. To this end, a literature review was carried out on oral cavity impression techniques and digital scanning with the aim of creating a prototype 3D scanner. A prototype was built for scanning solids, in which the object rotates around its axis and the scanner remains fixed during image acquisition. The scans were also carried out, going through the stages of acquiring and cropping the images, processing the colors and applying algorithms to obtain coordinates in order to create point clouds. As a result of this work, we obtained a 3D point cloud of a solid, using easy-to-acquire technologies. We can conclude that scan molding is faithful and, in the long term, less expensive than conventional molding.
Keywords: 3D scanning, Dentistry, Dental molding, Intraoral scanner, Biomedical engineering

INTRODUCTION

With continuous research and development, Biomedical Engineering has been progressively developing new technologies to aid diagnosis and treatment in the health sector. In dentistry, the importance of study models for treatment planning and monitoring is indisputable. And advances in the field of digital imaging have enabled modifications to the acquisition protocols for these records of the upper and lower dental arches, which is an example of the application of Biomedical Engineering (SUN *et al.*, 2018; LOIOLA *et al.*, 2019).

In dentistry today, dental arch impressions are a widely used technique in almost all specialties. It consists of obtaining as faithful a replica as possible of the patient's mouth, so that the dentist can study, diagnose and plan the clinical, prosthetic or surgical case without the patient being present (OLIVEIRA *et al.*, 2018). The most widely used impression procedure today is characterized by the introduction of a metal or polymer tray, filled with impression material (godivas, alginates or silicones), into the patient's mouth to obtain a negative of the shaped arch, called a mould. This is sent to a prosthetics laboratory where it will be filled with plaster (stone and/or special) to make a model of the patient's arch (VEIGA, 2018; CICCIÙ *et al.*, 2020).

However, some factors of this procedure in the oral cavity can cause discomfort for patients and costs for dentists. For the patient, the technique is uncomfortable because the pressure applied during molding and the amount of material used can cause the molding material to drain into the throat, causing discomfort and a feeling of regurgitation (ZAVANELLI *et al.*, 2016). For the dentist, the procedure can cost time, material and physical space. For dentists, it is necessary to send the mold to the prosthetics laboratory to produce the final model, which causes material alteration, mold distortion depending on the time elapsed between the molding and the production of the model, and a long wait due to transportation. Once the plaster model has been obtained, there is a risk of breakage when returning to the office, making it necessary to repeat the procedure and thus generating additional expenditure on molding material. In addition, storing the models while the case is being studied and planned requires a dedicated physical space, generating a cost that could be avoided with the possibility of digital storage (SUESE, 2020).

In order to solve these problems, new procedures have been developed for taking impressions, exploring different techniques for obtaining a model in digital format. One of these techniques is gaining importance on the dental scene, intraoral three-dimensional (3D) scanning, which consists of 3D scanning of the dental arch and creating a virtual model from the data acquired (VEIGA, 2018). Digital models are representations of dental arches and the relationship between them. They enable the virtual simulation of treatments, facilitating decision-making, and prove to be viable alternatives to conventional plaster models, due to the fidelity of most linear measurements when compared to the in vivo arch (MACK *et al.*, 2017; LOIOLA *et al.*, 2019). This technology also has other positive points when compared to traditional molding. One of these points is the absence of discomfort for the patient, since the procedure does not cause a sensation of regurgitation, which occurs with molding material (CICCIÙ *et al.*, 2020). Another positive aspect is that the final virtual model can be viewed immediately after scanning and, if necessary, 3D printed in the office, reducing the wait that used to be involved in transportation between the office and the laboratory. In addition, the cost of molding materials and physical storage space will also be reduced. In terms of advantages, the digital impression technique is more accurate than the conventional one (SUESE, 2020; CHANDRAN *et al.*, 2019).

However, this equipment is expensive to obtain, making it unfeasible to use in many dental practices (CICCIÙ *et al.*, 2020). Thus, there is a need to develop a device capable of performing intraoral 3D scanning using low-cost materials, with the aim of making this technology more accessible to dental professionals.

Based on these problems, this study proposes a literature review on the subject and the design and development of a prototype 3D *scanner* in the laboratory, with the aim of evaluating the influence of the scanning parameters on the digitized model, identifying the ideal conditions for intraoral application.

METHODOLOGY

Three samples were used for this work: a polymeric cup, a metal cup and a glass cup. We also used a microscope base, salvaged from the Directorate of Materials and Assets (DMP-UFRN), a line-type laser generator (with a wavelength of 650 nm and an output power of 5 mW), an iPhone XS cell phone camera (12 megapixels and 1080p video recording at 240 fps) and a rotating base (taken from an old CD player). A room in the laboratory was used as the environment for the tests, which allowed the variation between no light and artificial lighting by white fluorescent light.

To achieve the objective of this work, the steps illustrated in the following flowchart were followed (Figure 4).

The first stage of this study consisted of a literature review to analyze how commercial intraoral *scanners* work and to study materials and techniques for developing a low--cost 3D *scanner*. Articles were searched for in the Science Direct, PubMed, Web of Science and Periódicos Capes databases, using the following keywords: digital dental impressions, intraoral *scanners* and 3D scanning. 50

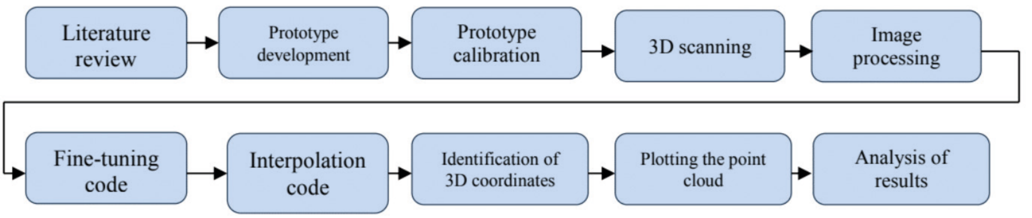

Figure 4 - Methodological process used to carry out the work

Source: Prepared by the author (2021)

Figure 7 - Description of the experimental prototype

Source: Prepared by the author (2021)

articles were found. Of these, 22 were chosen, 6 in Portuguese and 16 in English, from the last 5 years; all related to the aim of this study.

The second stage was to create the prototype 3D *scanner* (Figure 5a). To build it, we used a cell phone camera, a line-type laser and a base to support them. These materials were positioned so that, when scanning, the camera and laser remained fixed, while the sample to be scanned, supported on a rotating base (Figure 5b), rotated around its axis to capture the images

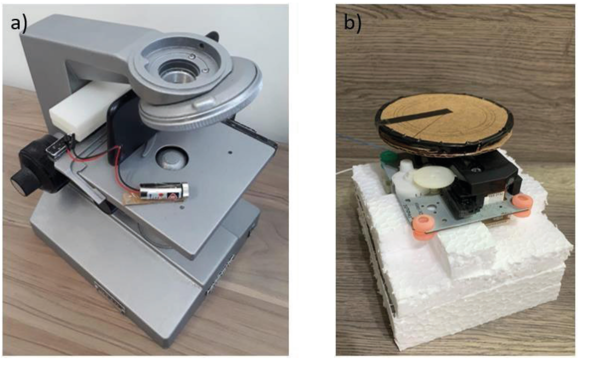

Figure 5 - Equipment used: (a) Prototype *scanner* (b) Rotating base

Source: Prepared by the author (2021)

The third stage of the work consisted of calibrating the prototype, based on the methodology used by Wispel *et al.* (2017), and carrying out the scans. To begin calibrating the equipment, the positions of the *scanner* and the rotating base were adjusted. The laser was positioned at an angle of 35 degrees to the camera, and the base was positioned so that its axis of rotation was aligned with the *scanner*, as shown in Figure 6. Next, the position of the laser beam on the rotating base was recorded, thus obtaining its behavior in the situation where there is no deformation, data used to calculate the distance by triangulation.

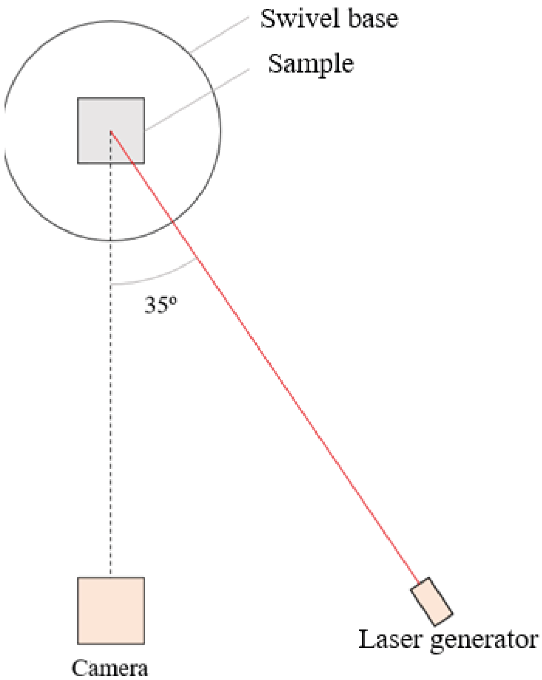

Figure 6 - Top view of the scanning system used
Source: Adapted from Wispel *et al.* (2017)

In order to assess the influence of the parameters of surface reflectivity, ambient lighting and laser beam focus, five different scans were carried out, varying the sample scanned and the scanning conditions. To assess surface reflectivity, three samples were scanned, all with similar geometries and curves (for better shape detection by the *scanner*) but with different surface characteristics. To assess the ambient lighting and focus of the laser beam, two scans were carried out with the polymeric material sample, varying one of these conditions in each of the scans. Figure 7 shows a model of how these scans were carried out.

Next, MATLAB *software* (MATrix LABoratory, version R2015a) was used to process the data acquired during the scan, from processing the images to plotting the point cloud. Image processing began by cropping all the images, highlighting only the area where the laser touches the sample. In order to

In order for the light beam to prevail in the image, color filters and sharpening and interpolation codes were applied (Figure 8). After this processing, the 3D coordinates were calculated. To do this, the deformation suffered by the laser beam was compared with the beam obtained in the calibration, and the distance between them was calculated. Once the 3D coordinates of the surface were known, the point clouds were plotted. Figure 9 shows a flowchart of the iterative process used to calculate the 3D coordinates.

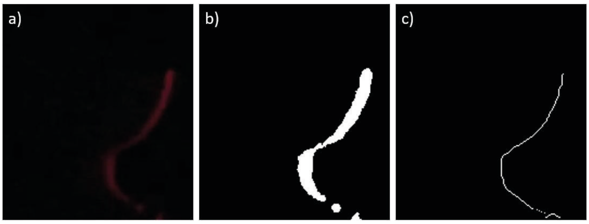

Figure 8 - (a) Image cut to highlight the beam; (b) Result of image color treatment; (c) Result of applying the thinning and interpolation codes
Source: Prepared by the author (2021)

Finally, the results were analyzed, evaluating the influence of the scanning parameters from the point clouds generated, in order to identify the ideal conditions for intraoral application.

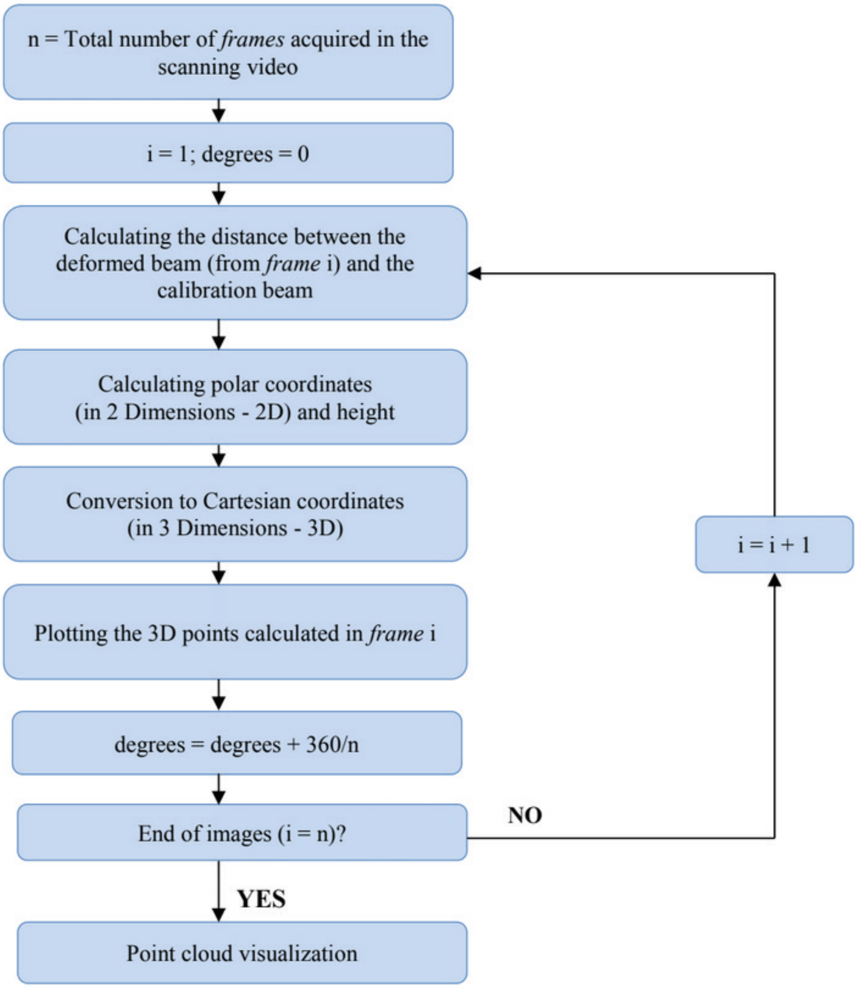

Figure 9 - Iterative process for calculating 3D points

Source: Prepared by the author (2021)

RESULTS AND DISCUSSIONS

Different models of intraoral *scanners* are currently available on the market. They vary, depending on the brand, in some characteristics such as scanning method, use of powder to reduce reflectivity, color identification and accuracy. Although they differ, most of the scanning methods used follow the same principle: optical scanning. In this way, a light is shone on the object of interest and the images obtained are processed in *software*, generating a point cloud and, by triangulating it, the 3D model is created (MANGANO *et al.*, 2017). The difference between the methods lies in the way the distance from the object is calculated. Models such as Lava C.O.S.® and True Definition are based on the active wavefront sampling technique, which calculates each point based on its behavior during a circular path traversed by the *scanner*. The iTero®, Zfx intrascan, Planmeca PlanScan® and TRIOS models use the principle of confocal microscopy, which is based on the focus of the image to determine depth. The *scanners* developed by Sirona Dental Inc., Cerec Bluecam® and Cerec Omnicam, calculate the distance of the object by triangulating the light, based on the principle that by knowing the positions and angles of two points of view it is possible to calculate the distance of the point of interest (ASWANI *et al.*, 2020; ZINT *et al.*, 2019; KACHHARA *et al.*, 2020). In addition to the me-

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thods that follow the optical scanning principle, there is also a small number of *scanners* that use ultrasound and optical coherence tomography methods, but these technologies are still under development and there are not a significant number of studies on them (ANDREEA-CODRUȚA *et al.*, 2019). Among the aforementioned models of commercially available intraoral *scanners*, only Lava C.O.S.®, True Definition and Cerec Bluecam® require powder to be applied to reduce the flexibility of the teeth. As for color identification, only Lava C.O.S.®, Zfx intrascan and Cerec Bluecam® do not generate the 3D model in color, i.e. they do not differentiate between structures that have different colors in the oral cavity, such as teeth and gums (ASWANI *et al.*, 2020; ZINT *et al.*, 2019). With regard to accuracy, although they are clinically satisfactory, there are differences between commercial models, but a conclusive comparison between them is difficult, as accuracy can be influenced by various factors, such as the amount of saliva, patient movement, dentist experience, scanning protocol and ambient lighting (LOIOLA *et al.*, 2019; ASWANI *et al.*, 2020).

Based on the review of 3D scanning, the line laser was chosen as the light source for the scans in this study. It offers the best price/result ratio, as it is clinically accepted and has a low purchase price. We used the light triangulation scanning method, which is used in the commercial *scanners* Sirona Dental Inc., Cerec Bluecam® and Cerec Omnicam.

In order to identify the most suitable parameters for scanning, the point clouds obtained were compared and the influence of these parameters on them assessed. According to the literature, scanning the polymeric material sample with a thin laser beam and in a dimly lit environment was expected to give the most accurate result of the proposed tests. Therefore, the scan carried out under these conditions was defined in this work as the basis for comparison. The resulting point cloud was very faithful to the scanned sample, as can be seen in Figure 10.

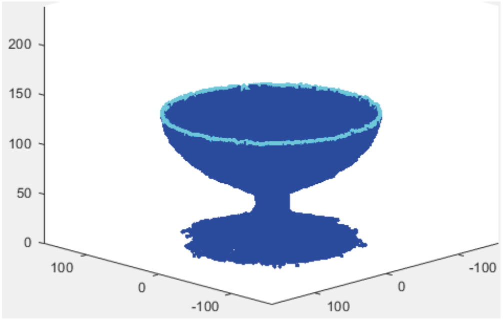

Figure 10 - 3D point cloud of the polymeric material sample

Source: Prepared by the author (2021)

The point clouds resulting from the scans of the metal and glass samples were not true to reality (Figure 11). Because they have reflective surfaces, the laser beam falling on them was scattered, making it difficult to identify the coordinates.

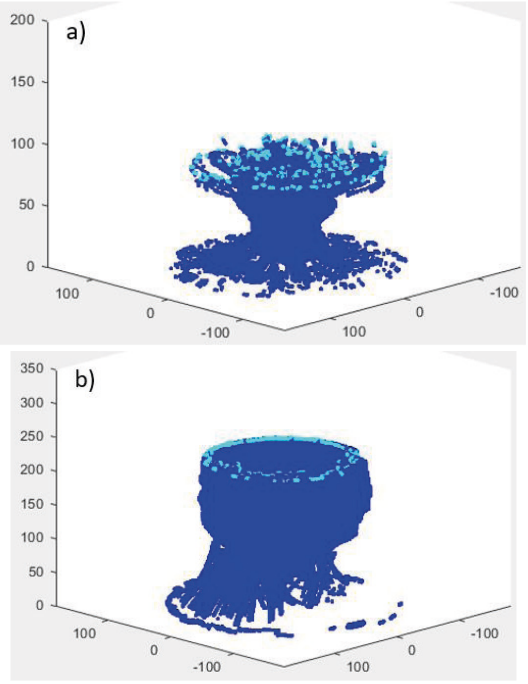

Figure 11 - 3D point clouds of (a) Metal and (b) Glass samples

Source: Prepared by the author (2021)

The ambient lighting was detrimental to the scan because it caused distortions in the point cloud, as can be seen in Figure 12. The difference observed between the results with and without lighting was due to the difficulty in identifying the coordinates in the more illuminated image, as the laser beam was not as evident.

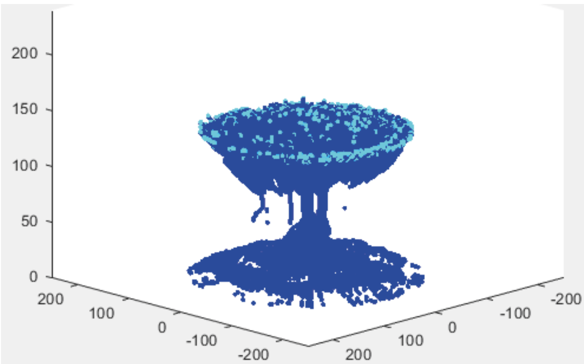

Figure 12 - 3D point cloud of the polymeric material sample in an illuminated environment

Source: Prepared by the author (2021)

Scanning using a diffuse laser beam, compared to the focused beam, generated a point cloud with less fidelity (Figure 13). This reduction in scanning quality occurs because the diffuse beam, being thicker, makes identifying the 3D coordinates in the image more complex.

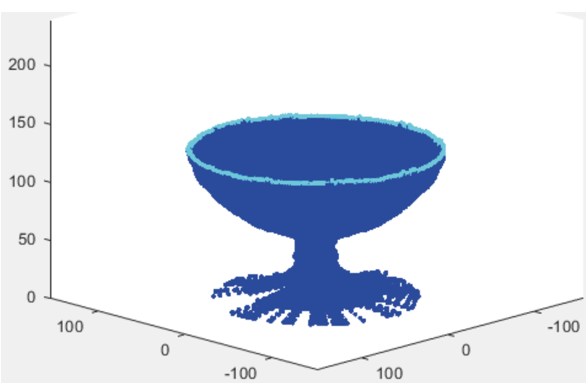

Figure 13 - 3D point cloud of the polymer material sample using diffuse laser beam

Source: Prepared by the author (2021)

CONCLUSIONS

Based on the results obtained, it can be concluded that scan casting is reliable and, in the long term, less expensive than conventional casting. The equipment developed in this work demonstrates that the technologies available on the market, most of which are expensive, can be replaced by low-cost and easy-to-obtain alternatives. The satisfactory performance of the scans is an indicator of the feasibility of using these materials for intraoral application.

It was clear that varying the parameters had a significant influence on the quality of the resulting point cloud. The reflectivity of the surface had a major influence, because the more opaque the material of the object being scanned, the more defined the laser beam will be. This avoids the scattering of the light beam, which can hinder image processing and, consequently, the calculation of 3D coordinates. Therefore, the polymeric material sample was better represented by the point cloud than the samples made up of reflective materials, metal and glass. The lighting in the room had a negative effect on the result, as the laser beam does not stand out as much in the image, making it difficult for the algorithms to identify it. This difficulty in identification causes errors in the calculation of coordinates, generating a cloud with distorted positions and not very faithful to the real object. Comparing the clouds generated by scanning with a diffuse laser and a focused laser, it can be seen that the focused laser creates a more faithful cloud. For the result to be more accurate, the laser beam needs to be well-focused, so that it is represented more clearly in the image, simplifying the identification of the coordinates. The scans carried out proved this, however, they also indicated that the influence of beam diffusion is small. Given that, despite having lower fidelity, the cloud generated using the diffuse laser was not as distorted.

It can therefore be concluded that in order to obtain greater fidelity in the model generated, scanning should be carried out in a low-light environment and using a thin laser beam. As for the surface of the object, the less flexible it is, the more accurate the result will be. Considering the intraoral context, the reflectivity of the oral cavity can negatively influence scanning. Therefore, to reduce the influence of this parameter, it is interesting to use powders to make the teeth more opaque.

Future work could continue with the development of the 3D *scanner*, adjusting the equipment and codes for the situation in which they will be applied, intraoral scanning, and taking into account what has been concluded in this work.

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