



COMPARATIVE ERROR ANALYSIS OF 3D- MODELING, -PRINTING AND - SCANNING METHODS USED IN ORTHODONTICS

Rabia Şimal Selamet
Dept. of Mechanical Engineering
Istinye University
Istanbul, Türkiye

Dr. Şenol Pişkin
Dept. of Mechanical Engineering
Istinye University
Istanbul, Türkiye

Abstract— The use of additive manufacturing in dentistry has exponentially increased, with dental model construction being the most common use of the technology. [1] This requires knowledge of the precision of these models. This is especially important for images used in clinical settings. This project proposal aims to conduct a comparative error analysis of 3D modeling, 3D printing, and 3D scanning methods used in orthodontics to measure the accuracy of 3D images and models used in dentistry and jaw surgery. Anonymized patient images (without identifying information) will be used in the project. The scanned images will be processed to create 3D anatomical models, which will then be printed using a 3D printer. The generated anatomies will then be scanned with a 3D scanner to create a new 3D model. The two resulting models (image processing and scanning results) will be compared by superimposing their axes. This mapping will enable quantitative and qualitative error analysis.

Keywords— Orthodontics, Clinical Image Processing, 3D Modeling, 3D Printing, 3D Scanning

I. INTRODUCTION

3D models provide significant benefits in pre-surgical planning, various biomedical research studies, and the education of medical students. With the development of 3D printing technology, its medical applications are expected to expand in the coming years with innovations such as reduced production costs, faster anatomical modeling, and the direct production of organs through bioprinting. [2]

This widespread use raises the question of how precise these models are. Considering that doctors work with models and perform surgeries, precision is a crucial parameter. This project will measure precision and also explore whether modeling is feasible with affordable products.

II. BACKGROUND

Certain steps are used when transferring any object into a three-dimensional environment, such as a chair, car, house, heart, jaw, etc. Since this project will focus on orthodontics and jaw surgery, this section provides information and examples based on medical research.

Similar method, which is explained in the method part applied were in orthognathic surgery for improving the predictability of surgical treatment procedures and outcomes, including data acquisition, image analysis, surgical simulation, surgical intervention, and outcome assessment Lin, HH., Chang, shows that models which used before “LeFort I osteotomy” and

“maxillomandibular complex surgery determined ranged from 0.18 to 0.33 mm in the maxilla and from 0.99 to 1.56 mm in the mandible, validation result [3]

Moreover, Narita M, Takaki T used a similar method, but they tested the mean amount of bleeding and mean operating time difference between with 3d models and without 3d models; we tested the deviation analyses between scanning method outcomes [4].

III. METHODS

A. Digital Twin Creation (Imaging, Segmentation, Reconstruction)

Image slices obtained in DICOM format will be compiled into a single directory and uploaded to 3DSlicer (BWH and the Slicer community) for processing. From the clinically obtained datasets (this study will use anonymized scanned patient images. These images are publicly available due to the studies conducted and the permissions obtained. Therefore, no additional ethics committee approval is required; the most appropriate set in terms of sequence and image quality will be determined, and the segmentation phase will begin. The anatomy will be inked on all slices. The inking process will begin with defining the outer borders and continue with automatic inking of the area within the borders. The three-dimensional anatomical structure will be revealed by combining the inked sections. Using this method, two-dimensional pixels will be converted to 3D voxels. The resulting 3D node set will then be saved in STL (stereolithography) file format (this file format is one of the most suitable standard formats for 3D modeling, editing, and 3D printing (folding, additive manufacturing).

B. 3D Printing

The 3D printer detects the file with the '.stl' extension and performs the printing process. 3D printers operate using a production method called additive manufacturing. While many raw materials are used for printing, thermoplastic materials, also known as filaments, are generally used. 3D printers require a three-dimensional model and design to function. Drawings created with a CAD (Computer Aided Design) program or objects scanned with a 3D scanner are exported with the '.stl' extension. [5]

3D printing technologies; [6]

- Stereolithography (SLA)
- Selective Laser Sintering (SLS)
- Fused Deposition Modeling (FDM)
- Multi Jet Fusion (MJF)

- PolyJet
- Direct Metal Laser Sintering (DMLS)

The printing process will be carried out using our university's printer. The printer supports FDM, SLA, DLP, and PolyJet technologies.

C. 3D Scanning

3D scanning is a quick and accurate method that enables the digitization of physical objects. It captures the object's x, y, and z coordinates to create a digital replica. Reverse engineering, which is utilized across various industries, aids in product development while reducing design and manufacturing costs and time. By using 3D scanners, the data collection process from physical objects can be significantly accelerated. [7]

3D scanning technologies: [8]

- Optical-based 3D scanning
- Laser-based 3D scanning
- Laser pulse-based 3D scanning
- Photogrammetry
- Structural illumination-based 3D scanning
- Contact-based 3D scanning

The optical scanning method used in orthodontics was used to compare the analysis results obtained from other scans. Photogrammetry and lidar scanning, considered more accessible and cost-effective methods, were also tested with different applications. It was observed that the lidar scan obtained with the KiriEngine yielded the best results.

Pre-Scan Preparation:

1_ Using a platform: It was used as a height because scanning very small objects was difficult.

2_ Attaching stickers to the platform: The influence of colorful stickers on the surface

As S. Rianmora and K. Nuamchit noted in their work, dark tones, especially green, were not detected by a 3D laser scanner in experiments using additive colors (RGB color model). While red stickers were detected quickly, they resulted in noise and unwanted areas. I applied this sticker-based scanning method suggested by the researchers in my own study and achieved better results, especially on larger objects. However, even with smaller objects, I achieved extremely clear and successful scanning results on the maxilla and mandible models I used in the project by positioning the stickers on the platform surface (because it was an organic model, attaching stickers to the surfaces was difficult).

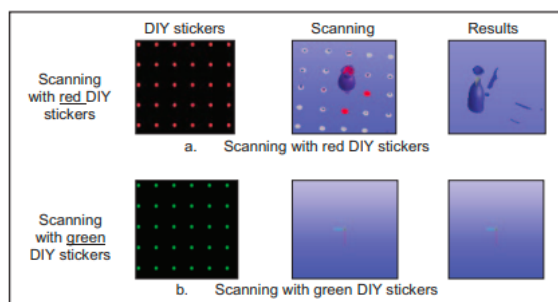


Figure 1: compared red (a.) and green (b.) DIY sticker that used in experiment

3_ Covering the surface with baby powder to prevent the object from shining.

4_ Proper lighting

Scanning Process:

Throughout the scanning process, scanning methods such as Optical-Based 3D Scanning, Laser Pulse-Based 3D Scanning, and Photogrammetry were used. When comparing photogrammetry and lidar results obtained with various apstore applications, lidar was observed to yield better results, so we continued with it. İstinye Dent Hospital resources were utilized for optical scanning.

Post-Scan Editing:

To prepare the scanned object for analysis Autodesk Meshmixer used. Some operations applied are cropping, resizing and smoothing



Figure 2: To avoid problems arising from the object's small size during scanning, the added platform was removed from the image.

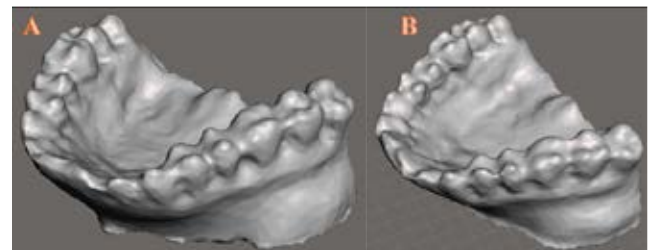


Figure 3: The scanned image was solidified, and sharp corners were smoothed. A: Light scanned image of the part coated with baby powder, edited in Meshmixer., B: Scanned image with dot stickers, edited in Meshmixer.

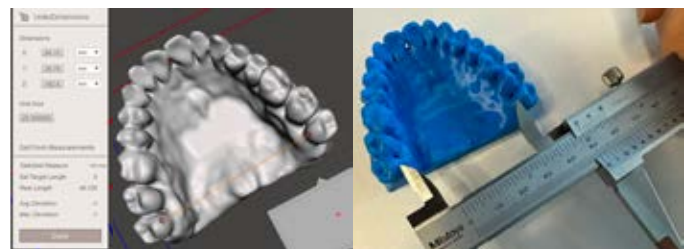


Figure 4: scanned image were measured using Meshmixer and compared with a caliper

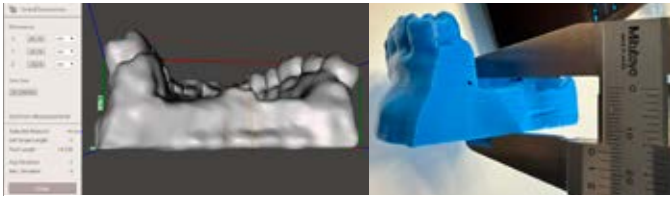


Figure 5: To verify the accuracy of the 3D printed and scanned images, the lengths of certain points in the scanned image were measured using Meshmixer and compared with a caliper.

D. Deviaation Analysis

Comparing the 3D model with the scanned model will be carried out using CatiaV5R21, a method similar to that used by ALPACA to characterize the evolutionary and ecological diversity of species. As shown in Figure a, two different 3D structures, blue and red, will be superimposed by matching their x, y, and z coordinates. The parts we define in different colors will reveal the differences between the structures after registration. These differences will provide us with sensitivity values. [10]

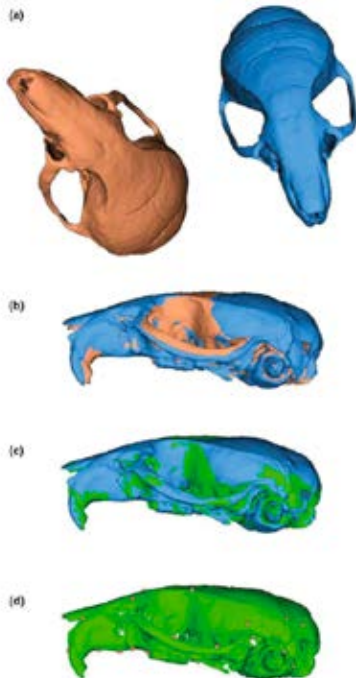


Figure 6: Image of two three-dimensional models mapping using ALPACA

Deviation Analysis Steps with Catia:

1. Start > Shape > Digitized Shape Editor
2. Import > Select to Files (Since the scanned image was 10^3 times smaller for the size control, a 10^3 scale was selected when uploading the scanned image to Catia, while the digital twin image was selected as 1.)
3. Mapping (performed by aligning the objects on top of each other).
4. Deviation Analysis > Choose Reference Part and Part to be Measured > Apply

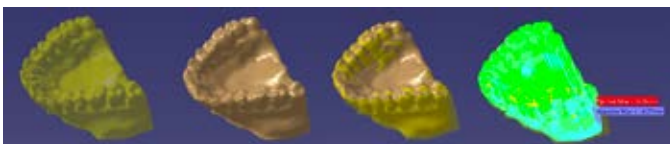


Figure 7: deviation analysis steps

IV. RESULT AND DISCUSSION

Material	Scanning method	Uygulama/ Maximum Sapma	Eksi yöndeki maksimum sapma (mm)	Pozitif yöndeki maksimum sapma (mm)
PLA	LIDAR SCANNING	Mandibula	-3,23	3,20
		Maxilla	-4,27	3,05
	OPTICAL SCANNING	Mandibula	-3,33	1,38
		Maxilla	0,79	2,65

In the comparison made for the maxilla, the deviation analyses resulted in the following order: optical scanning of the PLA model < lidar scanning of the PLA model.

When evaluated using the Lidar scanning method, the PLA model showed higher deviation values compared to optical scanning. This indicates that optical scanning provided more accurate results for the PLA model, especially for the maxilla, with lower maximum deviation values in both negative and positive directions.

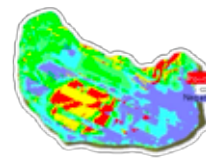


Figure 8: Pla based lidar scanning results of maxilla model.

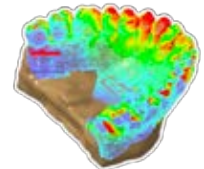


Figure 9: Pla based optical scanning results of maxilla model.

V. CONCLUSION

In conclusion, this study validated the theoretical accuracy range of orthodontic optical scanning methods under clinical-like conditions and benchmarked them against more affordable and readily available alternatives. Findings indicated that, when applied to a PLA model, the optical scanner achieved superior performance compared to competing systems.

ACKNOWLEDGMENT

I would like to thank İstinye University XR Labs for providing access to their facilities and İstinye Dent Hospital for granting the use of the optical scanner. I am also grateful to the team behind the KIRI Engine application for their guidance during the LiDAR scanning process, particularly for suggesting the application of baby powder on the model surfaces to improve scan quality. We would like to thank Asst. Prof. İpek Necla Güldiken for providing access to the scanning device used in this study, and Asst. Prof. Emine Nur Kahraman for sharing the CT images of the model.

This study has been supported by TÜBİTAK (The Scientific and Technological Research Council of Turkey) under project number 1919B012325675 -TUBITAK 2209A.



REFERENCES

- [1] Etemad-Shahidi Y, Qallandar OB, Evenden J, Alifui-Segbaya F, Ahmed KE. Accuracy of 3-Dimensionally Printed Full-Arch Dental Models: A Systematic Review. *J Clin Med*. 2020 Oct 20;9(10):3357. doi: 10.3390/jcm9103357. PMID: 33092047; PMCID: PMC7589154.
- [2] 1: Erdoğan, H. B. (2019). CERRAHİ UYGULAMALARDA MEDİKAL GÖRÜNTÜLEMENİN ÖNEMİ VE ÜÇ BOYUTLU ANATOMİK MODEL KULLANIMI. *Uludağ Üniversitesi Mühendislik Fakültesi Dergisi*, 24(3), 491-502. <https://doi.org/10.17482/uumfd.415607>
- [3] Lin, HH., Chang, HW. & Lo, LJ. Development of customized positioning guides using computer-aided design and manufacturing technology for orthognathic surgery. *Int J CARS* 10, 2021–2033 (2015). <https://doi.org/10.1007/s11548-015-1223-0>
- [4] Narita M, Takaki T, Shibahara T, Iwamoto M, Yakushiji T, Kamio T. Utilization of desktop 3D printer-fabricated "Cost-Effective" 3D models in orthognathic surgery. *Maxillofac Plast Reconstr Surg*. 2020 Aug 1;42(1):24. doi: 10.1186/s40902-020-00269-0. PMID: 32821740; PMCID: PMC7395922.
- [5] 3d printer nedir, nasıl çalışır, neler yapar <https://maker.robotistan.com/3d-yazici-printer/>
- [6] what are the different types of 3d printing? <https://www.futurelearn.com/info/courses/getting-started-withdigital-manufacturing/0/steps/184102>
- [7] Sarmah, M., Neelima, A. & Singh, H.R. Survey of methods and principles in three-dimensional reconstruction from two-dimensional medical images. *Vis. Comput. Ind. Biomed. Art* 6, 15 (2023). <https://doi.org/10.1186/s42492-023-00142-7>
- [8] Exploring the potential of 3D scanning in Industry 4.0: An overview Abid Haleem, Mohd Javaid, RaviPratap Singh, Shanay Rab, Rajiv Suman, Lal it Kumar , Ibrahim,,Haleem Khan <https://www.sciencedirect.com/science/article/pii/S2666307422000171>
- [9] S. Rianmora, K. Nuamchit, N. Vanasrivilai, P. Tantipiched and A. Rammuth, "Applying scanning techniques to create 3D model," IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, Japan, 2015, pp. 005217-005222, doi: 10.1109/IECON.2015.7392920. keywords: {Three-dimensional displays;Surface treatment;Solid modeling;Surface reconstruction;Data acquisition;Cameras;Design automation;reverse engineering;data acquisition;automated selective acquisition system;3D laser scanner},
- [10] ALPACA: A fast and accurate computer vision approach for automated landmarking of three-dimensional biological structures <https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/2041-210X.13689>