15th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering
and
3rd Conference on Imaging and Visualization
CMBBE 2018
P. R. Fernandes and J. M. Tavares (Editors)

Three dimensional evaluation of the holographic projection in digital model superimposition using HoloLens device

S.Talaat[1], A. Kaboudan[1], N. Ragy[1], C.Bourauel[2]

[1]Future University in Egypt
New Cairo, Egypt
egyptortho@gmail.com

[2]Department of Oral Technology, Bonn University
Bonn, Germany
bourauel@uni-bonn.

Keywords: Hololens, superimposition, digital dental models.

Abstract:

Objective: The aim of this study was to assess validity and reliability of 3D palatal superimposition of holograms of 3D digital dental models using a customized software (Ortho Mechanics Sequential Analyzer OMSA) installed on Microsoft Hololens device1-3, compared to the conventional OMSA application running on a regular computer screen. The OMSA software is developed to enable orthodontists to superimpose pre and post treatment digital dental models by selecting specific registration points selected by the user on stable anatomical landmarks. Then the orthodontist shall be able to analyze the achieved orthodontic tooth movement from the superimposed pre and post treatment 3D digital dental models. Methods: The sample consisted of pre- and post-treatment digital maxillary dental models of 20 orthodontic cases treated by maxillary expansion. For each case the pre- and post-treatment digital models were superimposed using hand gestures for marking the dental models holograms in mixed reality using the Microsoft Hololens. Then the same models were superimposed using the conventional landmark based method using OMSA software running on a regular computer 2 D screen. The same set of dental arch parameters was measured on the superimposed 3D data by the two software versions for comparison. Agreement in the superimposition outcomes among the two superimposition methods was evaluated with Dahlberg error (DE), intra class correlation coefficients (ICCs) using two way ANOVA mixed model for absolute agreement and Bland-Altman agreement limits (LOA). Results: Repeatability was acceptable for all variables based on the high obtained values of ICCs over 0.99 with a lower 95 % confidence limit over 0.95 for any variable. Also, the Dahlberg error (DE) ranged from as low as 0.14 mm up to 0.36 mm. The absolute error did not exceed 0.5 mm for any variable. Conclusions: Using the depth vision capabilities of the Microsoft HoloLens, 3D digital maxillary dental models can be visualized, get landmarks selected by stereovision and can be superimposed to interactively assess 3D orthodontic treatment outcomes.

Introduction:

The panacea of complete three-dimensional digital conversion has been prompted in particular by the advent of cone beam computerized tomography and the refinement of three-dimensional facial imaging. A further cog in this process is the advent of digital study model scanning.(1)

The replacement of plaster orthodontic models with virtual information has further potential benefits including: instant accessibility of 3D information without need for the retrieval of plaster models from a storage area; the ability to perform accurate and simple diagnostic set-ups of various extraction patterns; virtual images may be transferred anywhere in the world for instant referral or consultation; and objective model grading analysis, for example, for Peer Assessment Rating (PAR) or American Board of Orthodontics (ABO) scoring.(2)

Augmented reality (AR) is currently an attractive new technologic tool in the educational and interventional processes. AR is a new technology that supplements the real world with virtual objects that are generated digitally so that they appear to coexist in real space. AR is useful because it can enhance the user's perception and interaction with the real world. (3) Virtual objects are generated from specific graphical markers, which are transformed into moving 3D images through an optical reader attached to a digital program. The virtual objects display information that is not often directly detected by people with their own senses. The information reported by virtual objects helps the user perform real-world tasks.(4, 5)

AR technology was first introduced in 2003.(6) It has been used in the educational process in medicine. It is still in a rapidly progressing stage of development with further challenges. Despite its infancy, attempts to apply AR in surgery have been successful and promising. Neurosurgery, otolaryngology, and maxillofacial surgery are the main disciplines that have used this technology to navigate their specific surgical fields.(7, 8) It was used as well in operative dentistry by the aid of AR graphic markers that magnify and better visualize details of the images on the digital screens.(9) Nowadays AR is also used in medical interventions e.g in treatment of orbital hypertelorism, retinal and spine surgeries.(10-13) AR was also used in oral and maxillofacial surgeries.(4, 5, 14) Variable dental specialties are trying to make use of the AR tools to facilitate its operative procedures; e.g. in endodontics (15) and in Orthodontics.(16) A growing amount of Orthodontics research is based on 3D meshes or 3D volumes.(17, 18) Almost all use some type of computer applications to display, manipulate and analyze the 3D objects, which usually depends on selecting landmarks or arbitrary points on the 3D object. We should note that this type of 3D interaction is not the most appropriate, as we are just interacting with a 2D projected "*image*" of the real 3D object.(19) Actually, for the human visual perception system, this displayed image is not different perceptually from any other 2D image.

In order for the brain to build a real 3D solid object perception, it must rely on stereovision (Stereopsis or binocular vision), i.e. on using both right and left eyes to send the same image with two slightly different angles. In order to reproduce the depth perception experience, a computer program must generate two images, each as viewed from a camera aiming at slightly different angle than the other to the same point.(20) These two images are projected on each eye's retina through some type of device, in our case; the Microsoft HoloLens, to reproduce a genuine experience of 3D depth vision, thus allowing a correct perception and genuine experience of the displayed object.

Superimposition of a patient's 2D cephalograms is traditionally indicated whenever evaluation of orthodontic treatment and/or growth is needed. More recently, superimposing the 3D digital models or CBCT images makes it possible to assess these changes in a 3D manner. (21)

A recently developed software was introduced (Ortho Mechanics Sequential Analyzer OMSA) to enable visualization and superimposition of digital dental models. (22) The input of this program are the STL files derived from either laser scanned plaster casts or dental impressions. This software application is based on an innovative algorithm that reduces the amount of work needed to superimpose the 3D scanned dental models to a minimum (3 mouse clicks only).(23) The aim of this study was to assess validity and reliability of 3D palatal superimposition of holograms of digital dental models using OMSA software running on the Hololens device, compared to the conventional OMSA application running on a regular computer screen. Conventional OMSA application's validity and reliability have been proven in earlier research studies; (22)(23) so it was used as a gold standard for this research study.

Materials and Methods :

The sample for this study included the pre- and post-treatment digital maxillary dental models of 20 orthodontic patients treated with maxillary expansion using Hyrax palatal expanders as part of their orthodontic treatment. This sample was previously approved by the Indiana University Purdue University Indianapolis Institutional Review Board Committee. This sample was utilized in other research studies performed to confirm the reliability of linear and angular dental measurements with the OMSA software.(22) (23) Patients' age ranged from 8 to 15 years (12.3 +/- 1.9 years). Cases were treated by the palatal expanders over a period of 3 months. Models with any dental abnormalities, distortions or those treated by surgically assisted palatal expansion were excluded. This is because the distal end of the incisive papilla and midpalatal raphe were used as reference landmarks for superimposing the laser-scanned pre- and posttreatment digital maxillary models. Dental models were scanned using Ortho Insight 3D laser scanner (version 5.1, Motionview, Hixson, TN) with scanning resolution set at 20 μm. The scan data was then exported from the laser scanner in STL format file extension and the files were imported into the OMSA. Pre- and post-treatment digital models were superimposed with the OMSA software using the landmark-based method. The medial rugae area was considered a stable reference area to superimpose maxillary models for longitudinal cast analysis.(24) (25) In order to superimpose the pre and post treatment 3D digital maxillary models using OMSA on the conventional comuter screen, three points were registered on each of the pre and post treatment digital maxillary models: the first point was located at the distal end of the incisive papilla, the other two points were located arbitrary distal to the first point along the midpalatal raphe (Figure 1).

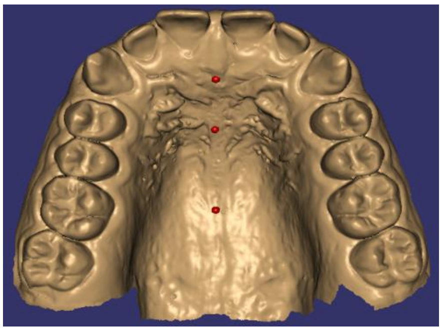

Figure 1. The three landmarks used for superimposition using OMSA on regular computer screen.

The exact algorithm by which the superimpostion was performed by these three registration points along the mid palatal raphe, was described in an earlier study. (23) The Microsoft Holo Lens (Microsoft, Redmond, Washington) was used to upload the STL files of the pre and post treatment 3D digital maxillary models (Figure 2).

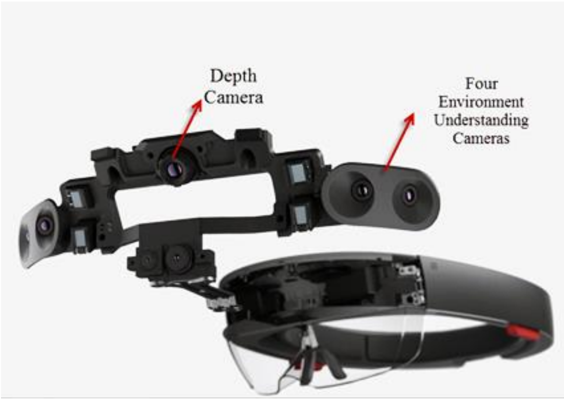

Figure 2. Microsoft Hololens

The HoloLens is capable of tracking the wearer hands and fingers gestures, and translate them to meaningful input intentions. Selection of landmarks on the digital dental models was done through free head movement, and clicking using finger gestures (Figure 3).

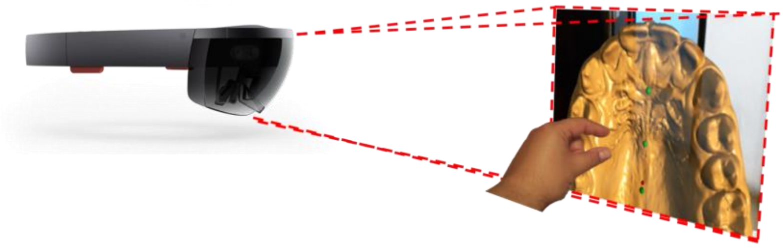

Figure 3. Using stereovision to locate landmarks by Hololens hand gestures.

The previous steps were successfully operated in augmented reality after installing OMSA on the Hololens; the three registration points were marked on the holograms of the pre and post treatment digital models using the hand gestures(Figure 4).

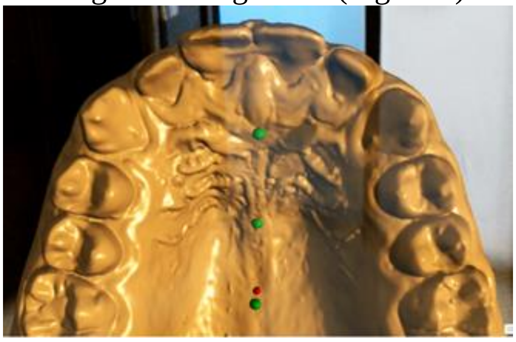

Figure 4. The three landmarks used for superimposition using OMSA installed on Hololens.

The superimposed models showed a real 3D assessment of the achieved orthodontic tooth movement in a 3D interactive hologram. Screen shots were taken from the video capture recorded while operating the OMSA software on the Hololens. (Figure 5)

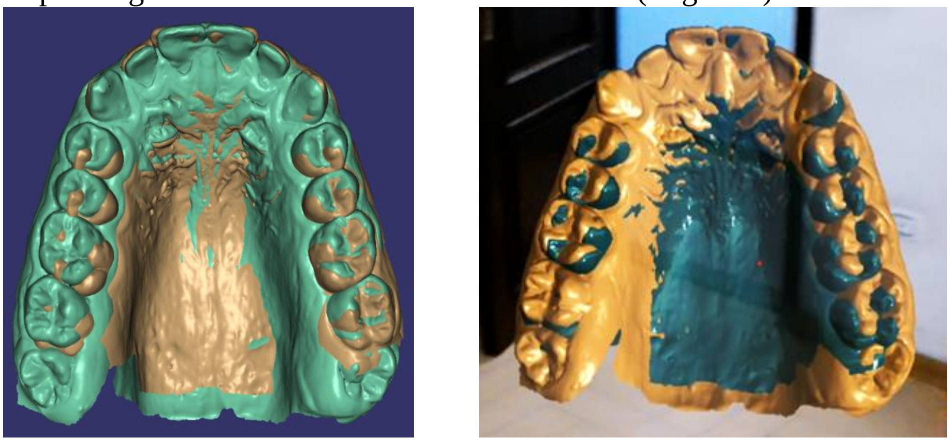

Figure 5. Superimposed pre and post treatment digital maxillary models as seen on :

A) Computer screen.

B) Microsoft Hololens.

The selected parameters (Figure 6 and Table 1) measured on the superimposed 3D data by the OMSA software on the computer screen and then the Hololens were compared.

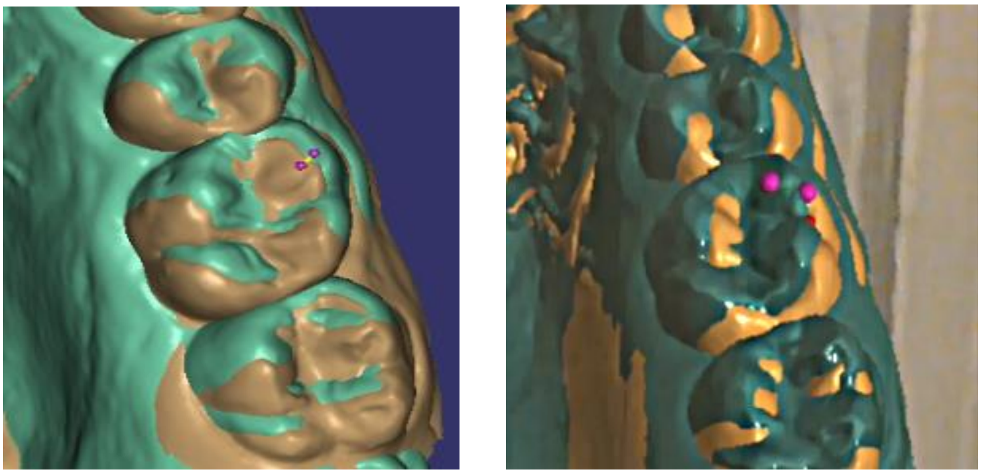

Figure 6.

Measurement of the distance between the maxillary left first molar MB cusp tips of the Superimposed pre- and post-treatment digital models using OMSA software,

A) On Computer screen.
B) On the Hololens

Table 1 : Parameters measured on the superimposed pre- and post-treatment models using the two softwares (OMSA,OMSA running on Microsoft Hololens)

R6 MB	Distance between the maxillary right first molar mesiobuccal cusp tips of the superimposed pre- and post-treatment digital models. Same parameter was measure on the left side (L6 MB).
R6 DB	Distance between the maxillary right first molar distobuccal cusp tips of the superimposed pre- and post-treatment digital models. Same parameter was measured on the left side (L6 DB).
R3	Distance between the maxillary right canine cusp tips of the superimposed pre- and post-treatment digital models. Same parameter was measured on the left side (L3).
R1	Distance between the midpoint of the incisal edges of the maxillary right central incisors of the superimposed pre- and post-treatment digital models. Same parameter was measured on the left side (L1).

R: right, L: left, MB: mesiobuccal, DB: distobuccal

Additionally, intercanine and intermolar widths were considered on the pre- and post-treatment Digital models and compared statistically so as to ensure the reliability of the scan data when viewed by the OMSA on the two interfaces; the computer and the Hololens. Measurements on the digital models on the computer screen were gathered from the previous studies that used the same sample. Measurements on the digital models using the Hololens were performed during this research study. Measurements on the Hololens were repeated once under the same conditions with a time interval of one week to assess interrater reliability. All measurements were made by the same examiner (S.T.). Reliability was determined as the extent to which the measurements on the digital models and the 3D images were repeatable under the same conditions. Validity was considered as the extent to which the measurements on the digital models by the on the two interfaces (computer screen and Hololens) yielded equal results. Intraclass correlation coefficients (ICCs) and Bland-Altman plots were used to evaluate the repeatability of the measurements for each method. Comparisons between the methods were made using repeated measures ANOVA. ICCs were also calculated to measure the agreement between the methods. A P value of ≤ 0.05 was considered statistically significant.

Results:

Reliability of each method and agreement among the two methods as measured by the ICCs was high. ICC ≥ 0.90 was reported for all measurements except for distance between superimposed R6 MB cusp tips with ICC of 0.88 using the Hololens. The computer based OMSA produced significantly higher distance between superimposed L6 MB cusp tip values than OMSA running on the Hololens ($P = 0.0489$) and OMSA ($P = 0.0117$) (Table 2). The statistically significant differences between some of the measured parameters among the two superimposition methods were clinically acceptable from the orthodontic point of view.

Table 2. Means, standard errors, significant differences, and levels of agreement between computer based OMSA and OMSA running on the Hololens.

		Mean	SD	Dahelberg error DE	Relative Dahelberg Error RDE	Mean of Differece (Reference - measured)	SD of the Difference	Bland & Altman Limits of Agreement (LOA) 95%confidence limits Lower	Bland & Altman Limits of Agreement (LOA) 95%confidence limits Upper	Intraclass Correlation Coefficient ICC	Intraclass Correlation Coefficient 95%confidence limits Lower	Intraclass Correlation Coefficient 95%confidence limits Upper
R6 MB cusp tip	OMSA software	4.13	1.33	0.24	5.7%	-0.16	0.30	-0.75	0.43	0.98	0.95	0.99
	OMSA Hololens[**]	4.29	1.35									
R6 DB cusp tip	OMSA software	4.00	1.40	0.17	4.2%	-0.09	0.22	-0.53	0.35	0.99	0.98	1.00
	OMSA Hololens	4.09	1.40									
L6 MB cusp tip	OMSA software	4.14	1.76	0.22	5.3%	-0.12	0.29	-0.69	0.46	0.99	0.98	1.00
	OMSA Hololens	4.26	1.71									
L6 DB cusp tip	OMSA software	4.09	1.56	0.19	4.6%	-0.09	0.26	-0.59	0.42	0.99	0.98	1.00
	OMSA Hololens	4.18	1.43									
R3 cusp tip	OMSA software	2.61	1.77	0.20	7.7%	-0.04	0.29	-0.61	0.53	0.99	0.98	1.00
	OMSA Hololens	2.65	1.88									
L3 Cusp tip	OMSA software	2.41	1.64	0.19	8.1%	0.01	0.28	-0.54	0.56	0.99	0.98	1.00
	OMSA Hololens	2.40	1.60									
R 1	OMSA software	1.29	1.14	0.19	14.7%	-0.10	0.26	-0.60	0.40	0.99	0.96	0.99
	OMSA Hololens	1.39	1.12									
L1	OMSA software	1.49	1.33	0.23	15.3%	-0.06	0.32	-0.69	0.57	0.99	0.96	0.99
	OMSA CVA	1.55	1.29									
Inter 3-3 pre ttt[8]	OMSA software	31.17	3.25	0.14	0.4%	-0.04	0.20	-0.42	0.34	1.00	1.00	1.00
	OMSA Hololens	31.21	3.20									
Inter 3-3 post ttt	OMSA software	33.51	3.29	0.17	0.5%	0.03	0.25	-0.46	0.51	1.00	1.00	1.00
	OMSA Hololens	33.48	3.25									
Inter 6-6 pre ttt	OMSA software	45.60	3.66	0.21	0.5%	-0.04	0.29	-0.62	0.53	1.00	1.00	1.00
	OMSA Hololens	45.64	3.54									
Inter 6-6 post ttt	OMSA software	52.15	4.21	0.36	0.7%	0.20	0.48	-0.74	1.13	1.00	0.99	1.00
	OMSA Hololens	51.96	4.27									

Discussion:

As technology evolves, new interfaces define how developers will build the products that we will use. In the early days of computing, we used printers, display screens, mouse and keyboard. These are powerful concepts that almost 50 years later we are still using them. More recently, touchscreens have driven the smartphone revolution. . We are currently in a rare moment where we can see an approaching shift in technology. Augmented reality is one of these shifts e.g. Hololens. Hololens has 3 forms of interaction : gaze, gesture and voice. In this research study, the gaze and gesture capabilities of the Hololens were used.

It is important to understand the major technical challenges the design of HoloLens solves. The first is how to locate and track the wearer in his 3D environment; this is known as position tracking. The second is how to know what the wearer is looking at, and this is known as orientation tracking.(26, 27)

Another important issue is how the wearer will interact with the HoloLens. Microsoft's solution is to use gestures. In order to solve these problems, the HoloLens collects information about the surrounding environment and objects using multiple sensors of different types as inertial measurement unit, environment understanding cameras, depth camera, ambient light sensor, microphones, high definition color camera, and others. For holographic output, the HoloLens use see-through holographic optics to beam the 3D scene directly to the user eyes.

Various processors are built in the HoloLens; in addition to the CPU (Central Processing Unit) and GPU (Graphics Processing Unit), Microsoft introduced the HPU (Holographic Processing Unit). The HPU is designed to collect all information from the multiple cameras and sensors in real-time.

The aim of this study was to test a digital dental model software installed on the Microsoft Hololens for better visualization and interactive assessment of orthodontic treatment outcomes. A recently developed software program, the Ortho Mechanics Sequential Analyzer™ (US patent 61/771,328), was introduced to enable visualization and superimposition of dental models. The input for this program is the STL files derived from either scanned plaster models or dental impressions. This software application is based on an innovative algorithm that reduces the amount of work needed to superimpose the 3D scanned dental models to a minimum (3 mouse clicks only). The OMSA successfully worked in augmented reality using the Hololens. The three registration points were marked on the holograms of the pre and post treatment digital models using the hand gestures. In this research, we substituted the standard 2D Monitor and Mouse Clicks by the HoloLens, which acts as a "*3D Input Device*" and as a "*stereovision Output (display) Device"* in the same time.

Using the depth vision capabilities of the HoloLens, the user can now inspect any 3D object with a genuine stereovision experience, and select the required landmarks, as he would do in real life directly interacting with the physical plaster model. Selection is done through free head movement, and clicking using finger gestures.

In addition to validity and reliability of the measures performed on the superimposed digital maxillary models holograms, the holograms enabled the user to perform a real 3D assessment of the achieved orthodontic tooth movement in 3D interactive scenes.

Conclusion:

Using the depth vision capabilities of the Microsoft HoloLens, 3D digital maxillary dental models can be visualized, get landmarks selected by stereovision and can be superimposed to interactively assess 3D orthodontic treatment outcomes.

Rerferences:

1. Hirogaki Y, Sohmura T, Satoh H, Takahashi J, Takada K. Complete 3-D reconstruction of dental cast shape using perceptual grouping. IEEE transactions on medical imaging. 2001;20(10):1093-101.
2. Fleming P, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. Orthodontics & craniofacial research. 2011;14(1):1-16.
3. Azuma RT. A survey of augmented reality. Presence: Teleoperators and virtual environments. 1997;6(4):355-85.
4. Zhu M, Chai G, Zhang Y, Ma X, Gan J. Registration strategy using occlusal splint based on augmented reality for mandibular angle oblique split osteotomy. Journal of Craniofacial Surgery. 2011;22(5):1806-9.
5. Lin YK, Yau HT, Wang I, Zheng C, Chung KH. A novel dental implant guided surgery based on integration of surgical template and augmented reality. Clinical implant dentistry and related research. 2015;17(3):543-53.
6. Meisner J, Donnelly WP, Roosen R. Augmented reality technology. Google Patents; 2003.
7. Shuhaiber JH. Augmented reality in surgery. Archives of surgery. 2004;139(2):170-4.
8. Botden SM, de Hingh IH, Jakimowicz JJ. Meaningful assessment method for laparoscopic suturing training in augmented reality. Surgical endoscopy. 2009;23(10):2221-8.
9. Espejo-Trung LC, Elian SN, Luz MA. Development and Application of a New Learning Object for Teaching Operative Dentistry Using Augmented Reality. Journal of dental education. 2015;79(11):1356-62.
10. Zhu M, Chai G, Lin L, Xin Y, Tan A, Bogari M, et al. Effectiveness of a Novel Augmented Reality-Based Navigation System in Treatment of Orbital Hypertelorism. Annals of plastic surgery. 2016;77(6):662-8.
11. Rieke N, Tan DJ, Amat di San Filippo C, Tombari F, Alsheakhali M, Belagiannis V, et al. Real-time localization of articulated surgical instruments in retinal microsurgery. Medical image analysis. 2016;34:82-100.
12. Elmi-Terander A, Skulason H, Soderman M, Racadio J, Homan R, Babic D, et al. Surgical Navigation Technology Based on Augmented Reality and Integrated 3D Intraoperative Imaging: A Spine Cadaveric Feasibility and Accuracy Study. Spine. 2016;41(21):E1303-e11.
13. Borgmann H, Rodriguez Socarras M, Salem J, Tsaur I, Gomez Rivas J, Barret E, et al. Feasibility and safety of augmented reality-assisted urological surgery using smartglass. World journal of urology. 2016.
14. Katic D, Spengler P, Bodenstedt S, Castrillon-Oberndorfer G, Seeberger R, Hoffmann J, et al. A system for context-aware intraoperative augmented reality in dental implant surgery. International journal of computer assisted radiology and surgery. 2015;10(1):101-8.
15. Bruellmann DD, Tjaden H, Schwanecke U, Barth P. An optimized video system for augmented reality in endodontics: a feasibility study. Clinical oral investigations. 2013;17(2):441-8.
16. Aichert A, Wein W, Ladikos A, Reichl T, Navab N. Image-based tracking of the teeth for orthodontic augmented reality. Medical image computing and computer-assisted intervention :

MICCAI International Conference on Medical Image Computing and Computer-Assisted Intervention. 2012;15(Pt 2):601-8.
17. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Diagnostic accuracy and measurement sensitivity of digital models for orthodontic purposes: A systematic review. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2016;149(2):161-70.
18. Lisboa Cde O, Masterson D, da Motta AF, Motta AT. Reliability and reproducibility of three-dimensional cephalometric landmarks using CBCT: a systematic review. Journal of applied oral science : revista FOB. 2015;23(2):112-9.
19. Cockburn A, McKenzie B, editors. Evaluating the effectiveness of spatial memory in 2D and 3D physical and virtual environments. Proceedings of the SIGCHI conference on Human factors in computing systems; 2002: ACM.
20. Verhoef BE, Vogels R, Janssen P. Binocular depth processing in the ventral visual pathway. 2016;371(1697).
21. Garib DG, Calil LR, Leal CR, Janson G. Is there a consensus for CBCT use in Orthodontics? Dental press journal of orthodontics. 2014;19(5):136-49.
22. Talaat S, Kaboudan A, Breuning H, Ragy N, Elshebiny T, Kula K, et al. Reliability of linear and angular dental measurements with the OrthoMechanics Sequential Analyzer. American Journal of Orthodontics and Dentofacial Orthopedics. 2015;147(2):264-9.
23. Talaat S, Kaboudan A, Bourauel C, Ragy N, Kula K, Ghoneima A. Validity and reliability of three-dimensional palatal superimposition of digital dental models. European journal of orthodontics. 2017.
24. Chen G, Chen S, Zhang X, Jiang R, Liu Y, Shi F, et al. Stable region for maxillary dental cast superimposition in adults, studied with the aid of stable miniscrews. Orthodontics & craniofacial research. 2011;14(2):70-9.
25. Choi D-S, Jeong Y-M, Jang I, Jost-Brinkmann PG, Cha B-K. Accuracy and reliability of palatal superimposition of three-dimensional digital models. The Angle orthodontist. 2010;80(4):685-91.
26. Doisy G, Ronen A, Edan Y. Comparison of three different techniques for camera and motion control of a teleoperated robot. Applied ergonomics. 2017;58:527-34.
27. Chao TH, Liu HK. Real-time optical holographic tracking of multiple objects. Applied optics. 1989;28(2):226-31.