Accuracy of Low-Cost Alternative Facial Scanners: A Prospective Cohort Study.

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Abstract

Introduction: Three-dimensional facial scan images have been showing an increasingly important role in peri-therapeutic management of oral and maxillofacial and head and neck surgery cases. Face scan images can be open using optical facial scanners utilizing line-laser, stereophotography, structured light modality, or from volumetric data obtained from cone beam computed tomography (CBCT). The aim of this study is to evaluate, if two low-cost procedures for creating a three-dimensional face scan images are able to produce a sufficient data set for clinical analysis.

Materials and methods: 50 healthy volunteers were included in the study. Two test objects with defined dimensions were attached to the forehead and the left cheek. Anthropometric values were first measured manually, and consecutively, face scans were performed with a smart device and manual photogrammetry and compared to the manually measured data sets.

Results: Anthropometric distances on average deviated 2.17 mm from the manual measurement (smart device scanning 3.01 mm vs. photogrammetry 1.34 mm), with 7 out of 8 deviations were statistically significant. Of a total of 32 angles, 19 values showed a significant difference to the original 90° angles. The average deviation was 6.5° (smart device scanning 10.1° vs. photogrammetry 2.8°).

Conclusion: Manual photogrammetry with a regular photo-camera shows higher accuracy than scanning with smart device. However, the smart device was more intuitive in handling and further technical improvement of the cameras used should be watched carefully.

Introduction

Obtaining three-dimensional (3D) surface images of the face and the head area is becoming increasingly popular in various specialties. Generated images are used for preoperative planning and treatment simulation, patient education, postoperative evaluation, research, and in fabricating computer aided planning/computer aided design (CAD/CAM) products, such as customized facial masks and surgical guides. Despite the rapid advances in scanning technology, there are only few professional camera systems available which are dedicated solely to face and head scanning for the medical practice. Currently several variations of these facial scanning devices are available either as mobile scanners (such as Artec Eva [Artec 3D, Luxembourg], M4D Scan [Rodin4D, Mérignac, France], Vectra H1 [Canfield Scientific Inc., Parsippany, USA]), or as stationary scanning devices (such as FaceScan3D [3D-Shape GmbH, Erlangen, Germany, Vectra M3/XT [Canfield Scientific Inc., Parsippany, USA], 3dMD Face System [3dMD LLC, Atlanta, USA]). Furthermore, facial scanners are distinguished according to the optical technique used for the generation of the 3D data set. Stereophotogrammetry is based on taking several photos by multiple cameras from different angles, which are then merged to a three-dimensional model[1]. An additional method called “triangulation” is a similar technical device but using structured light to capture the images. The capturing technology is based on the projection of parallel stripes on the patient's face to create a pattern which is then captured by cameras in order reconstruct the 3D model based on mathematical algorithm calculated from the distortion of the light pattern 15. These different capturing techniques have various advantages which has been extensively evaluated in literature. These face scan are able to produce 3D face scan images with an accuracy ranging from 0.32 to 0.89 millimeters (mm)[2–6].

Nevertheless, all current face scanners bear certain inherent disadvantages. First of all, the cost of a professional face scanner currently ranges from 9,000 to 95,000 EUR, and is thereby relatively expensive even to established clinical centers and research institutions. Furthermore, some devices require frequent calibrations and professional handling. Another drawback of stationary scanning devices is the need for a large space and a permanent installation room [7]. The above-mentioned drawbacks lead to the urge of finding a cheap and yet accurate alternative to obtain suitable face scan images. Smart devices could be one promising option. In 2017, Apple Inc. introduced the TrueDepth camera in the iPhone X, which allowed identification using face recognition. According to Apple Inc., 30,000 invisible points are projected, analyzed and an infrared image of the face is recorded. In addition to their wide availability, a great advantage of smart devices is their lower acquisition costs compared to most existing professional face scan systems.

Another promising technique that can be used to create 3D facial models is called photogrammetry (manual photogrammetry). It is based on the digital fusion of a series of overlapping two-dimensional single photos of the face in order to create a 3D object from several or only one camera [8]. A special photogrammetric method is the “structure from motion” (SfM) photogrammetric range imaging technique. In order to find matches between the images, certain points are tracked from one image to the next. In the SfM imaging technique, this process happens fully automatically, whereas with conventional photogrammetry, manual determination of matching points is necessary for the calculation of a 3D surface.

When reviewing all the current imaging modalities, this ultimately leads to the question if these rapidly evolving optical technologies can also be used to create 3D models of the face while meeting the high demands expected from medical applications. The aim of this study was therefore to evaluate the accuracy of 3D facial images that were obtained using mobile smart devices to conventional photogrammetry optical scanning devices, and therefore to compare two alternatives and inexpensive scanning methods for creating 3D surface scans of the human face.

Materials And Methods

Participants

Fifty healthy volunteers were included in this prospective study. Gender distribution was 22 to 28 (m:f). The mean age of the study population was 44.4 ± 16.4 years, with a range from 18 to 83 years. Exclusion criteria for the recruitment of participants were visible facial deformities and excessive facial hairiness (beard). The study protocol was approved by the institution’s ethical committee (083/20ek). The study was performed in accordance with the declaration of Helsinki. A written informed consent was obtained from all volunteers prior to the conduction of the study.

Face scan and data acquisition

For better objectivity and comparability to the existing literature, anthropometric values and two geometric bricks were scanned and measured. Adequate exposure was ensured during recording and image capturing, and the volunteers were instructed to keep a natural head position and show a neutral facial expression and not to move the head. Reproducible anthropometric points and distances in the faces were measured manually. Distances between the medial canthi, the lateral canthi, the nasal alae and angles of the mouth were measured (Fig. 1). Distances between the anthropometric points on the volunteer's face were measured manually with a caliper. The data was documented and set as standard since they represent the real values.

Afterwards, two gaming blocks (The LEGO Group, Billund, Denmark) with uniformly defined dimensions of 31.8 x 15.8 mm and angles of 90 degrees were used as markers. To get an even surface, the blocks were filled with plaster. The two test items were then attached to the participant's face. One was placed in the middle of the forehead, the other on the left cheek (Figs. 2 and 3). An iPad Pro (3rd generation, Apple Inc., Cupertino, USA) with Heges App (version 1.2.4, Developer: Marek Šimoník) served as the smart device for capturing the images. The iPad Pro was for 1,099 EUR, and the price of the software was 2.99 EUR. The software uses the device's front camera to scan the face. For this, the device was always moved in the same way from the frontal center of the face to the sides in order to record all sides of the face. The data was then exported as a stereolithography file (.stl).

Next, for the manual photogrammetry, a video recording of the face was made with a digital single-lens reflex camera (DSLR) Nikon D5500 (Nikon Corporation, Tokyo, Japan) with a suitable lens AF-P DX NIKKOR 18–55 mm (f/1:3.5-5.6G VR, Nikon Corporation). Starting from the forehead, the camera was moved clockwise around the face in order to capture all sides of the face from different perspectives. The file was then saved in QuickTime File Format (.mov). The applied hardware was available for 899 EUR, the software was open source.

Post processing and measurement

The .stl file from the smart device was imported into MeshLab (version 2020.03, Consiglio Nazionale delle Ricerche, Rome, Italy) for Windows. After that, artifacts were removed and the model was cut to the edges of the face. The file was then exported again in .stl- format.

The video files of the manual photogrammetries were imported into VLC Media Player (version 3.0.11 Vetinari, VideoLAN, Paris, France) for Windows. Using the scene filter function, the single frames of the video were saved as an image file in the Joint Photographic Experts Group format (.jpg). Then blurred photos were sorted out from the data set in order to use only suitable photos for the calculation of the 3D model. Next, a point cloud was calculated from the adjusted data set using a visual structure from motion system (SfM) GUI application- VisualSFM (version 0.5.26, Developer: Changchang Wu) for

Windows. This was saved as a Polygon File Format (.ply) and imported into MeshLab. Same as the model created with the smart device, artifacts were removed and the face was cut to the edges. Then, the normals of the point cloud were calculated and a surface reconstruction was carried out. This result was also exported in .stl- format.

The program GOM Inspect 2019 (Hotfix 8, GOM GmbH, Braunschweig, Germany) for Windows was used for measurement of the parameters in both data sets. Because the .stl- data sets did not have a reference for adequate measuring of distances, the models were scaled based on the length of bricks attached to the forehead (31.8 mm). For this purpose, a fitting plane was constructed on the frontal side of the test item with output of the dimensions. Then all further fitting planes were constructed using selected points on the outer edges of both test items. These planes were calculated using the Gauss best-fit method based on 3 sigma of the selected points in order to correct outliers. So, there were five fitting levels per test item at the end. Next, the remaining dimensions of the two frontal fitting planes of both test items except the scaled length were documented and all possible angles between the constructed fitting planes were measured. This gives eight angles per test item. Furthermore, above-mentioned distances based on the anatomical landmarks were measured as a 2-point distance after manual selection of the respective points. The scans are shown in Fig. 2 for the smart device and Fig. 3 for photogrammetry.

Statistical Analysis

The statistical analysis was performed using IBM SPSS Statistics (version 25, IBM Corporation, New York, USA). The dependent t-test was applied to the metric values. Means and standard deviation was calculated for all values. Normal distribution was calculated and confirmed via evaluation of Q-Q-plot.

Results

Deviation of the anthropometric distances was calculated for all previously defined data sets, leading to a total of 8 values. On average, they deviated 2.17 mm from the manual measurement, whereas photogrammetry showed a higher accuracy than smart device scanning (deviation 1.34 mm vs. 3.01 mm). However, all of the 8 deviations were statistically significant.

In the measurement of the length and width of the bricks, two out of three values differed significantly in smart device measurement in comparison to the defined values and equally two out of three significantly differed in manual photogrammetry (Table 1 and 2).

Table 1
Comparison of the face-scan with a smart device and manual measurements and defined length and angles respectively.

	Smart device (SD)	Manually / defined (SD)	p values
Anthropometric values			
medial canthi	34.12 (± 3.16)	31.00 (± 3.47)	0.004
lateral canthi	98.40 (± 7.15)	94.39 (± 6.67)	0.000
nasal alae	36.95 (± 3.86)	35.72 (± 3.62)	0.000
mouth	55.74 (± 4.61)	52.03 (± 3.91)	0.000
Dimensions of the gaming brick			
Width forehead	15.20 (± 0.96)	15.80	0.000
length cheek	32.41 (± 1.52)	31.80	0.007
width cheek	16.06 (± 1.10)	15.80	0.105
Angles of the gaming brick			
Left to top plane forehead	98.12 (± 5.93)	90	0.000
Right to top plane forehead	97.60 (± 4.45)	90	0.000
Right to bottom plane forehead	90.80 (± 3.49)	90	0.111
Left to bottom plane forehead	94.20 (± 4.98)	90	0.000
Left to front plane forehead	105.69 (± 8.56)	90	0.000
Top to front plane forehead	118.56 (± 10.71)	90	0.000
Right to top plane forehead	98.94 (± 6.86)	90	0.000
Bottom to front plane forehead	107.73 (± 6.36)	90	0.000
Left to top plane cheek	90.09 (± 3.26)	90	0.842
Right to top plane cheek	91.08 (± 3.81)	90	0.050
Right to bottom plane cheek	94.01 (± 4.72)	90	0.000
Left to bottom plane cheek	91.17 (± 3.65)	90	0.028
Left to front plane cheek	97.74 (± 6.31)	90	0.000
Top to front plane cheek	98.81 (± 6.90)	90	0.000
Right to top plane cheek	95.87 (± 8.95)	90	0.000
Bottom to front plane cheek	104.78 (± 7.45)	90	0.000

Table 2
Comparison of the face-scan with manual photogrammetry and manual measurements and defined length and angles respectively.

	Photogrammetry (SD)	Manually / defined (SD)	p values
Anthropometric values			
medial canthi	32.27 (± 2.83)	31.00 (± 3.47)	0.000
lateral canthi	92.06 (± 6.41)	94.39 (± 6.67)	0.000
nasal alae	34.28 (± 3.30)	35.72 (± 3.62)	0.000
mouth	52.35 (± 4.34)	52.03 (± 3.91)	0.000
Dimensions of the gaming brick			
Width forehead	16.52 (± 1.01)	15.80	0.000
length cheek	32.09 (± 1.02)	31.80	0.050
width cheek	17.19 (± 1.12)	15.80	0.000
Angles of the gaming brick			
Left to top plane forehead	89.45 (± 3.14)	90	0.224
Right to top plane forehead	90.72 (± 3.70)	90	0.173
Right to bottom plane forehead	89.43 (± 3.29)	90	0.229
Left to bottom plane forehead	90.76 (± 3.17)	90	0.097
Left to front plane forehead	91.61 (± 4.81)	90	0.022
Top to front plane forehead	92.19 (± 5.06)	90	0.004
Right to top plane forehead	89.29 (± 4.15)	90	0.233
Bottom to front plane forehead	93.72 (± 5.49)	90	0.000
Left to top plane cheek	90.68 (± 3.32)	90	0.156
Right to top plane cheek	91.83 (± 3.41)	90	0.000
Right to bottom plane cheek	89.21 (± 5.47)	90	0.313
Left to bottom plane cheek	90.48 (± 4.33)	90	0.434
Left to front plane cheek	90.25 (± 5.83)	90	0.763
Top to front plane cheek	90.93 (± 3.62)	90	0.076
Right to top plane cheek	93.11 (± 8.09)	90	0.009
Bottom to front plane cheek	100.30 (± 9.76)	90	0.000

For the geometric reliability, a total of 8 angles on each brick and for each face scanner were measured, leading to a total number of 32 values. The majority of them (19 out of 32) showed a significant difference to the 90° angle of the bricks. 13 of these accounted for smart device scanning and 6 for manual photogrammetry. The average deviation was 6.5°. However, manual photogrammetry (mean of 2.8° deviation) showed a higher accuracy in comparison to smart-device capturing (10.1° deviation) (compare Table 1 and 2). Especially in the smart device, the angles appeared to be too large.

For manual photogrammetry, 151.18 (+/- 30.62) pictures were taken per .stl- data set.

Discussion

The use of a face scanner to obtain 3D facial images has become increasingly popular during the last decades especially in the field of maxillofacial and aesthetic surgery. There are several fields of utilization of face scan images, such as in evaluation of volumetric changes after surgical interventions, preoperative and /or postoperative evaluation of surgeries. However, several different models exist, with a wide range of quality of the data set and the consecutive reconstructed 3D face.

Camison et al. calculated the distances between several marked points in the face and it resulted in 136 distances in total. The deviation was on average 0.84 mm [2]. Other authors used heatmaps to determine a mean absolute difference, resulting in an accuracy from 0.32 to 0.71 mm. The same technique was also used for an accessory iPad hardware sensor, resulting in an accuracy of 1.33 mm [3, 6]. In our study cohort, we achieved an average deviation of 1.34 mm with photometry and 3.01 mm with a smart device respectively. Since the distance between anthropometric points were measured, the results are comparable to Camison et al., however they are technically not comparable to the measurement of a heatmap. Using lego bricks Modabber et al. determined a mean deviation from the 90° angles of 0.42° to 35.41° in a professional face-scanner [4]. Surprisingly, the results from both techniques in our study achieved better results in the measurement of the angles than professional face scanner. The reason might not be related the capturing device of the 3D data, but rather the software of the processors, because they tend to smoothen edges. This effect was also seen in our cohort of patients measured with the smart device. The angles were larger than in reality, which is probably attributed to the smoothening effect.

In our study cohort, manual photogrammetry with a regular photo-camera was more detailed and more accurate than the smart device. However, the major disadvantage in manual photogrammetry is the data acquisition. There were on average 151.18 ± 30.26 photos needed and at they need to be fused. Thus, it does not appear to be a likeable solution for daily routine. Nonetheless, in distinct cases, for example in a research setting, it might be a usable solution.

In contrast, the scan with the smart device is more user friendly and intuitive but leads to a less accurate reconstruction of the face. On a long term, smart devices are likely to further improve in terms of camera technique but also in terms of processing software. It appears to be likeable that in near future these devices can deliver 3D data sets comparable to professional cameras. Thus, a regular control with every new generation of smart device-cameras should be performed.

In daily clinical practice, one purpose of 3D face-scan is the production of individual protective masks for athletes. Cazon et al. compared two scanners and found a deviation of the mask from the scanned surface between − 2.0 and 2.7 mm and an average of 0.18 and 0.15 mm for two scanning devices [9]. In a case series report by Steiner et al., the face mask was produced conventional by plaster impression and it showed an average deviation of 1.57 mm with a maximum of 5.62 mm. It was then compared with a production based on a 3D scan. Latter mentioned showed an average deviation of 0.99 mm and a maximum deviation of 6.18 mm. 10 They conclude that differences of a few millimeters do not seem to reduce comfort or protective effect of these masks [10]. In our study, the average deviation of the anthropometric measurements ranged from 1.34 mm to 3.01 mm. Thus, it could be clinical usable the production of protective masks as well.

Amornvit et al. also described the use of an iPhone for face-scanning. They used Bellus3D as an App for data acquisition[11]. Further potential software programmes are Trnio, Capture and Scandy Pro. However, in evaluation phase prior to the conduction of the study, all of the obtained images obtained with Bellus3D APP were either not precise enough, or showed problems with data export. So, the authors chose Heges App as the most suitable for an iOS device. Android driven or other devices were not considered in the study, but certainly provide also reliable alternatives.

Finally, it is important to mention, that pictures from photogrammetry do not appear as smooth as 3D pictures from the smart device as we previously described. Nonetheless, it is important to note for daily practice. If the scan is needed for patient education, a smoothened surface is desirable and minor discrepancies in length or angles might not be a relevant problem. In contrast, for research issues, the more detailed the face-scan is and the less deviation is seen, the better it is. Thus, photogrammetry seems a favorable option in those cases.

Conclusion

Manual photogrammetry with a regular photo-camera shows higher accuracy then scanning with smart device but with much higher complexity level during processing to obtain the 3D face images. Thus, it might be more suitable especially for usage in research settings. Smart device scanning is more intuitive and could be an option in patient education. This technology is undergoing massive technical development and a clinical revaluation in a few years seems to be conceivable.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethic Committee of Leipzig University (083/20 ek). This report followed the Declaration of Helsinki on medical protocol and ethics. Written informed consent to participate was obtained by all patients.

Competing interests

The authors declare that they have no conflicts of interest.

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Consent for publication

All authors consent for publication. Written informed consent to publish personal data and use their images was obtained by all patients.

Availability of data and material

All data can be shared

Acknowledgements

Not applicable.

Authors contributions

All authors have reviewed the paper and contributed to the manuscript. A. Bartella, J. Laser, A. Sander and B. Lethaus designed the study and were involved in the scanning. D. Halama, M. Neuhaus, J. Laser, N. Pausch put much effort in 3D measurement and statistical calculations. Kamal, R. Zimmerer, A. Bartella had a major role in study organization and draft writing.

References

1. Lekakis G, Claes P, Hamilton GS 3rd, Hellings PW. Three-Dimensional Surface Imaging and the Continuous Evolution of Preoperative and Postoperative Assessment in Rhinoplasty. Facial Plast Surg. 2016;32(1):88–94.
2. Camison L, Bykowski M, Lee WW, Carlson JC, Roosenboom J, Goldstein JA, Losee JE, Weinberg SM. Validation of the Vectra H1 portable three-dimensional photogrammetry system for facial imaging. Int J Oral Maxillofac Surg. 2018;47(3):403–10.
3. Knoops PG, Beaumont CA, Borghi A, Rodriguez-Florez N, Breakey RW, Rodgers W, Angullia F, Jeelani NU, Schievano S, Dunaway DJ. Comparison of three-dimensional scanner systems for craniomaxillofacial imaging. J Plast Reconstr Aesthet Surg. 2017;70(4):441–9.
4. Modabber A, Peters F, Kniha K, Goloborodko E, Ghassemi A, Lethaus B, Holzle F, Mohlhenrich SC. Evaluation of the accuracy of a mobile and a stationary system for three-dimensional facial scanning. J Craniomaxillofac Surg. 2016;44(10):1719–24.

5. Peters F, Mohlhenrich SC, Ayoub N, Goloborodko E, Ghassemi A, Lethaus B, Holzle F, Modabber A. The use of mobile 3D scanners in maxillofacial surgery. Int J Comput Dent. 2016;19(3):217–30.
6. Verhulst A, Hol M, Vreeken R, Becking A, Ulrich D, Maal T. Three-Dimensional Imaging of the Face: A Comparison Between Three Different Imaging Modalities. Aesthet Surg J. 2018;38(6):579–85.
7. Tzou CH, Artner NM, Pona I, Hold A, Placheta E, Kropatsch WG, Frey M. Comparison of three-dimensional surface-imaging systems. J Plast Reconstr Aesthet Surg. 2014;67(4):489–97.
8. Luhmann T: Nahbereichsphotogrammetrie Grundlagen, Methoden und Anwendungen. 3rd ed. Berlin; 2010.
9. Cazon AAJ, Paterson A, Bibb R, Campbell RI. Customised design and manufacture of protective face masks combining a practitioner-friendly modelling approach and low-cost devices for digitising and additive manufacturing. Virtual Physical Prototyping 2015. 2014;9(4):251–61.
10. Steiner TRS, Steegmann J, Fischer H, Hölzle F. Moderne Gesichtsprotektionsmasken im Profi-Ballsport – eine Fallstudie. Dtsch Z Sportmed 2017(02):43–46.
11. Amornvit P, Sanohkan S. The Accuracy of Digital Face Scans Obtained from 3D Scanners: An In Vitro Study. Int J Environ Res Public Health 2019, 16(24).

Figures

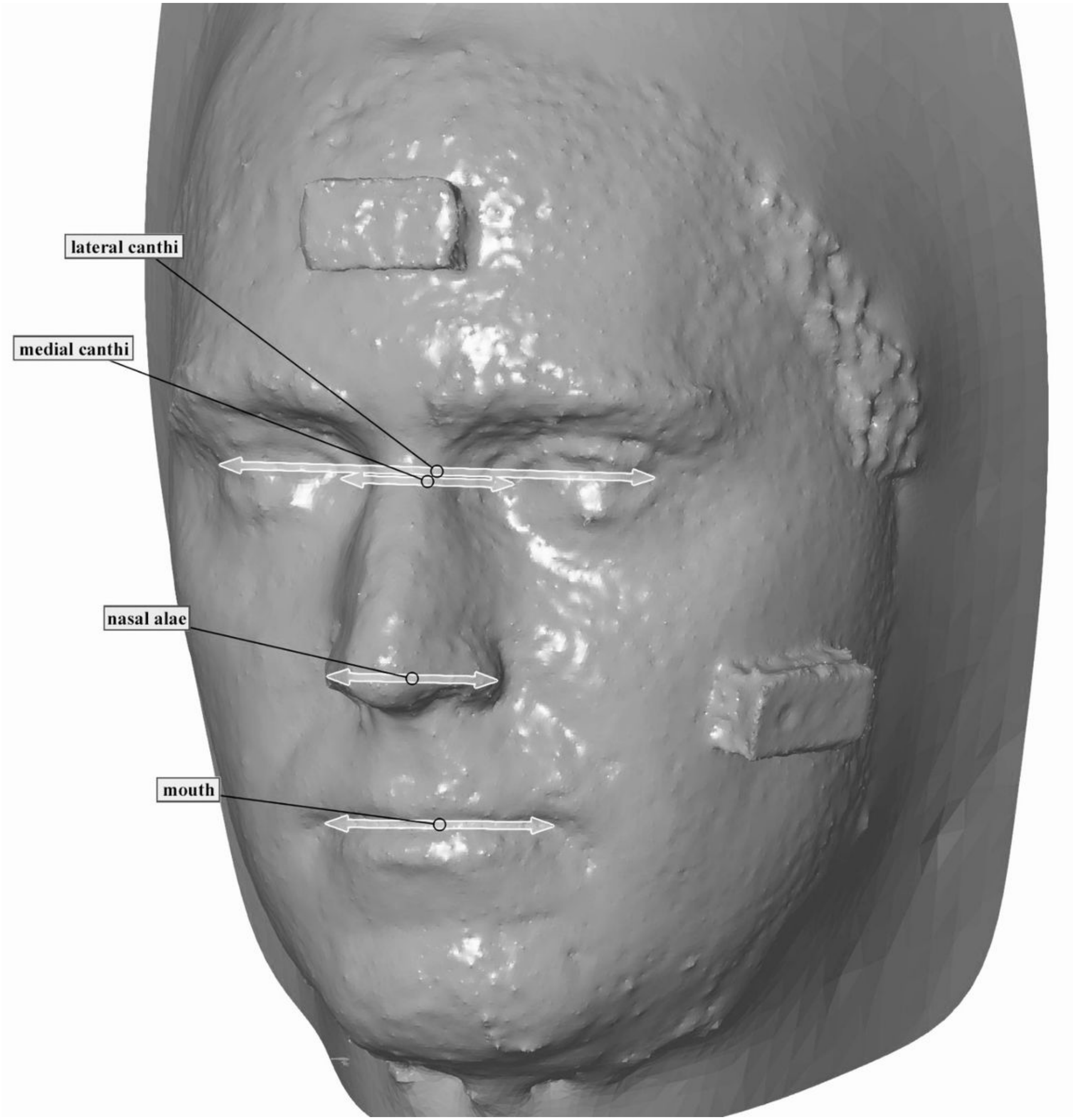

Figure 1

anthropometric distances that were measured manually and virtually.

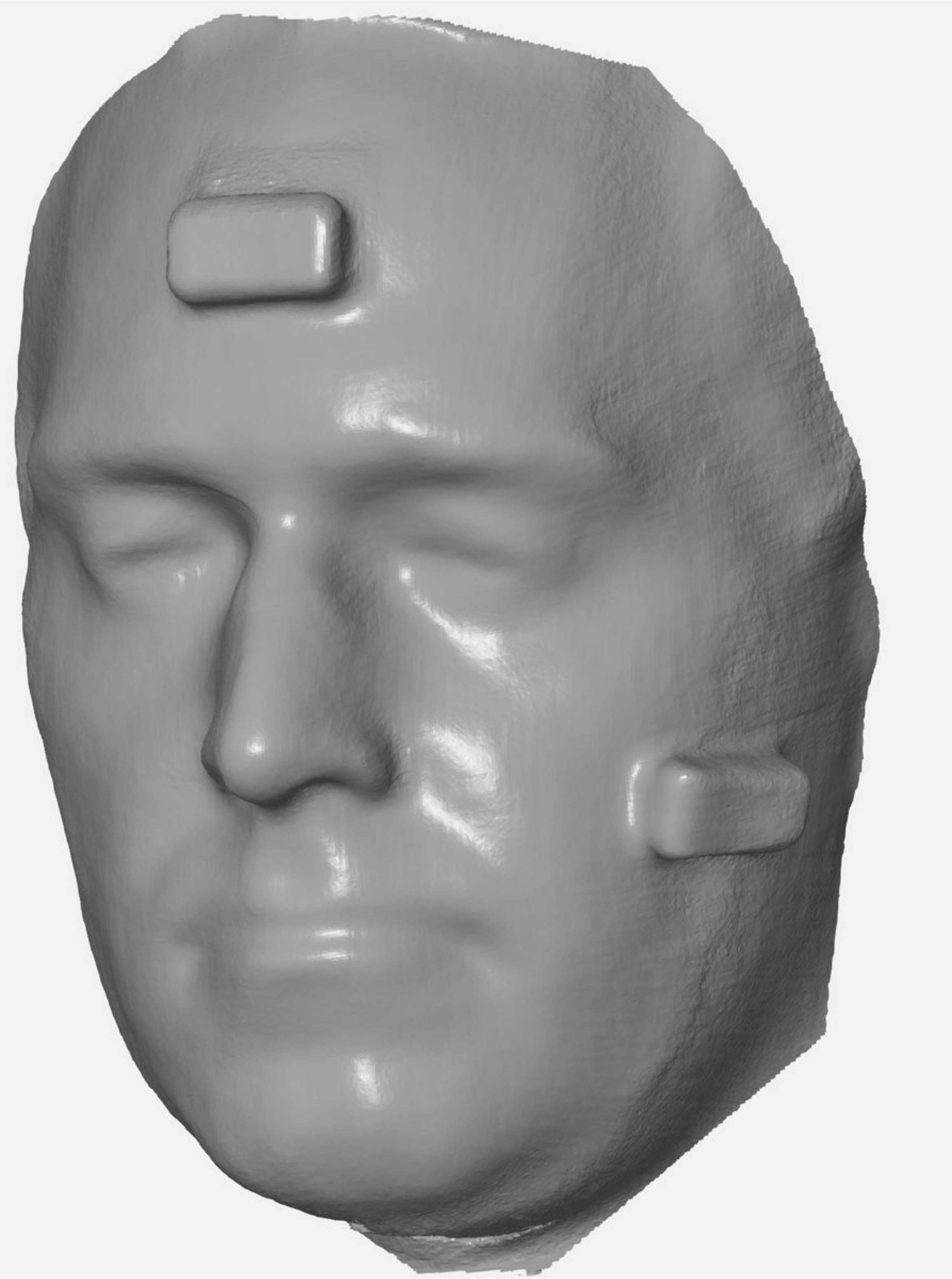

Figure 2

Face-scan created by a smart device. The appearance of the face is smoother. However, also the bricks are affected by the smoothening and appear to be less accurate.

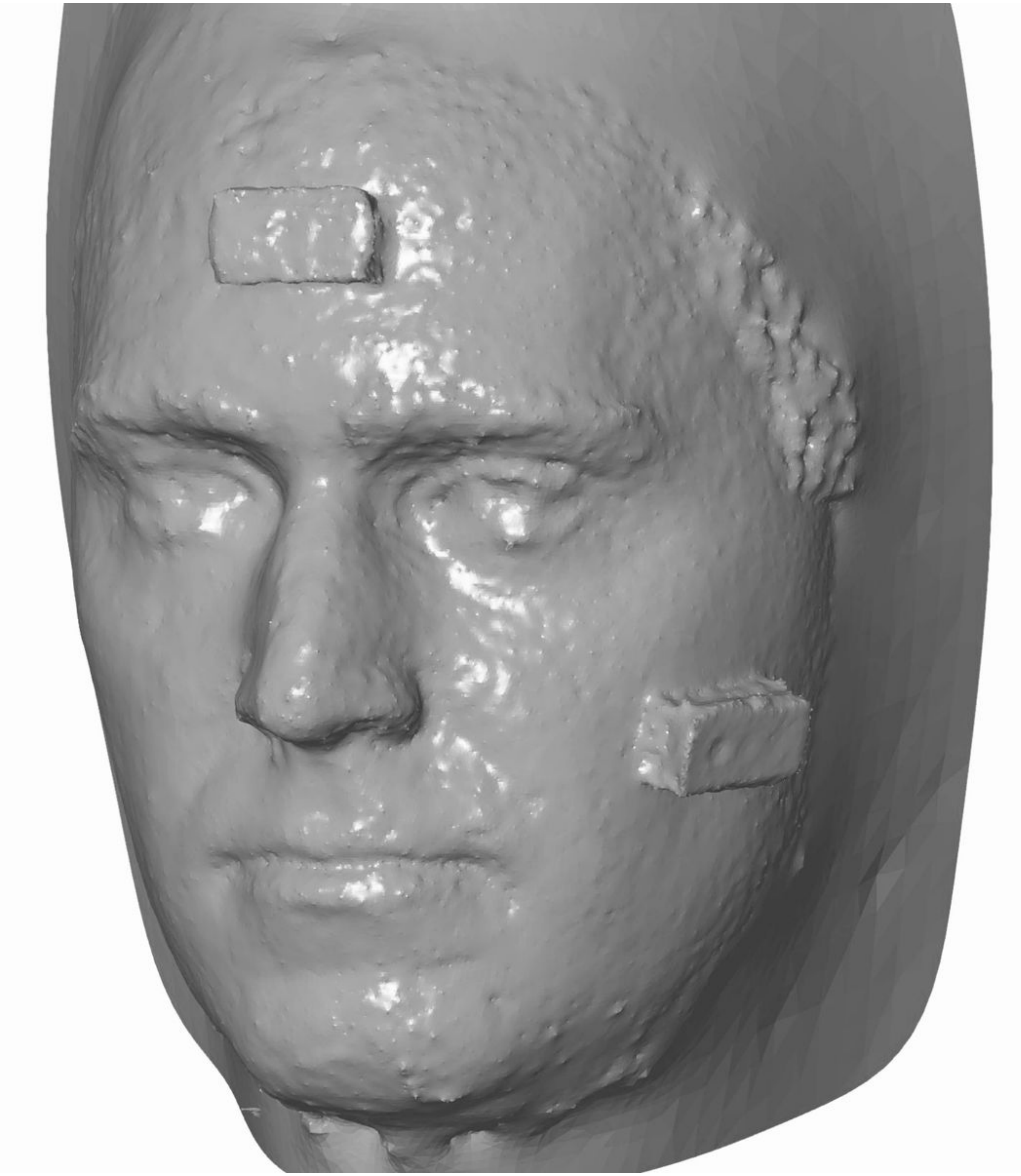

Figure 3

Face-scan created by manual photogrammetry. For this particular scan, the fusion of a total of 151.18 ± 30.26 pictures was necessary. Notable is the edgy surface of the face.