

Comparison of Optical Handheld 3D Scanners Suitable for Prosthetic and Orthotic Applications

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Abstract

3D scanning technology is globally frequently used in the field of prosthetics and orthotics. Techniques and methods using 3D scanners make it easier and faster for CPOs (Certified prosthetic orthotist) to obtain important data for prosthetic and orthotic device design.

Nevertheless, in low-income countries, this is still a new approach, and some CPOs might find it hard to trust. Also, the prices of some of these 3D scanning devices and data processing software are too high. Because of these issues, modern methods are being neglected and the whole prosthetic device designing process isn't advancing.

The aim of this study is to compare optical handheld 3D scanners of different brands, designs, and price ranges. A polystyrene model of the human torso with predetermined geometric forms will be scanned with multiple handheld optical 3D scanning devices. For the precision evaluation of the 3D scanners and hand measurement it is necessary to position the reference forms in a way that it will allow measurement by both methods. Selected dimensions must include all three axes of the cartesian coordinate system, so it will be possible to scanners precision in all individual axes. Scanning will be performed by one person in a room with stable lighting and room conditions. The torso model will be scanned by individual scanners and measured by hand 3 times and a mean value and standard deviation will be calculated. The geometric forms will be also used for the alignment of obtained 3D models in VGStudio Max software, which will be used for the analysis process. Distances between predetermined forms on the obtained 3D models will be evaluated. These nominal values will be compared with the actual values from the torso model, which were measured by hand.

The quality and surface precision of actual obtained 3D models will be compared to determine the minimal or ideal requirements of optical handheld 3D scanners for the use in the field of prosthetics and orthotics.

Keywords: 3D scanning, optical scanners, precision analysis, prosthetics, orthotics

1. Introduction

The Scanning the body surface using 3D scanners is, from a practical point of view, an adequate method for designing orthotic devices. It is contactless, faster, more detailed, and more convenient for the patient compared to the traditional method of data collection, and in the case of portable hand-held 3D scanners, the patient's presence at a special workplace is not required [1-5]. The innovation of the technological process of collecting measured data consists in the use of 3D scanning and computer processing of scanned data into a 3D model, which replaces the gypsum positive. Thanks to this technological process, it is possible to achieve greater accuracy, speed of device production, a new level of comfort for the patient and functionality for the field of prosthetics and orthotics (P&O) [6-9].

Still to this day most CPOs (Certified Prosthetists Orthotist) in practice think that 3D scanning is not a reliable method for data obtainment, although there is a lot of research regarding the accuracy and precision of professional and low-cost 3D scanning devices and systems. Rosicky et al. compared several high and low-end 3D scanners for P&O application. From their study it can be stated that with greater precision comes greater application in practice. Nevertheless, they concluded that low-cost 3D scanners can still be used for less precise applications, e.g., for braces and prosthetic covers [10].

Lately there has been a new trend in 3D scanning for P&O practice by using smartphones and 3D scanner apps. Smartphones like iPhone generation X and higher have TrueDepth cameras which can be used as 3D scanners when an appropriate app is used. Smith et al. compared pre precision of measurements acquired by a freely downloadable smartphone app and a conventional full-body scanner with those measured with a flexible tape at the same anatomic sites. It has been shown that a free downloadable smartphone app is fully capable of providing precise and accurate body circumference measurements [11].

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Nightingale et al. developed and validated a low-cost framework for clinical 3D scanning of the external ear using photogrammetry and a smartphone camera. Their results show that the smartphone-based photogrammetry methodology for 3D external ear model acquisition is accurate to $1,5\pm 0,4\text{mm}$ and were $71\pm 14\%$ complete compared with those from a gold standard reference scanner [12]. Mai et al. compared accuracy of face models acquired by a smartphone face scanner app with those scanned with a professional 3D facial scanner. Overall, the accuracy of smartphone compatible face scanners in 3D facial acquisition was not comparable to that of professional optical scanning systems, but it was still within the clinically acceptable range of $<1,5\text{mm}$ in dimensional deviation [13]. Rudy et al. compared the precision of an iPhone X 3D scanner with a freely downloadable scanning app to a commonly used high-end 3D scanner in plastic surgery. As a result, the iPhone X can produce three-dimensional facial scans with an accuracy resulting in an average difference of less than 0.5 mm when compared against images obtained with the high-end 3D scanner. They also state that the iPhone X outperforms most portable three-dimensional data acquisition systems currently available on the market when considering accuracy and precision [14].

The aim of this study is to compare the surface precision and accuracy of 3D models acquired with several smartphone 3D scanning apps and a low-cost handheld 3D scanner to a gold-standard 3D model acquired by a professional 3D scanner suitable for application in P&O.

2. Methods

2.1. 3D scanning

This research is based on a surface precision comparison of actual and nominal 3D models acquired by 3D scanning. In this case, the model that is being scanned and compared is a milled mold of the human torso with applied landmarks on the posterior side of the model (figure 1) for 3D model fitting purposes. Polystyrene balls covered with permanent 3D scanning spray (Attblime, Bensheim, Germany) were used as landmarks. The nominal, or gold-standard model is a 3D model of the scan of the torso created with the use of the high-end professional scanner Artec Eva (Artec 3D, Luxembourg, Luxembourg). The actual models are created by using cheaper 3D scanning systems or devices which in this research is a Creality CR-SCAN 01 (Creality 3D Technology Co., Ltd., Shenzhen, China) handheld 3D scanner and a tablet, more specifically a 3rd generation iPad Pro 11' (Apple Inc., Cupertino, CA, USA) containing a TrueDepth front camera. Scanning with the iPad is performed through two 3D scanning apps, of which the first is a freely downloadable app called 3d Scanner App (Laan Labs, New York, NY, USA) and the second is COMB (Comb O&P, Chardon, OH, USA), which is a 3D scanning app officially suitable for the use in P&O. The scanning was done in an artificially lighted room with a constant temperature of 24°C . All required procedures for 3D scanning were followed.



Fig. 1 A milled mold of the human torso with applied landmarks on the posterior side of the model

All acquired 3D models have been postprocessed in Meshmixer (Autodesk, San Rafael, California, USA) CAD (Computer Aided Design) software and the actual to nominal model comparison has been performed in VGStudio MAX (Volume Graphics, Heidelberg, Germany) software.

2.2. Actual to nominal model comparison

Two methods of actual to nominal model alignment in VGStudio MAX have been considered:

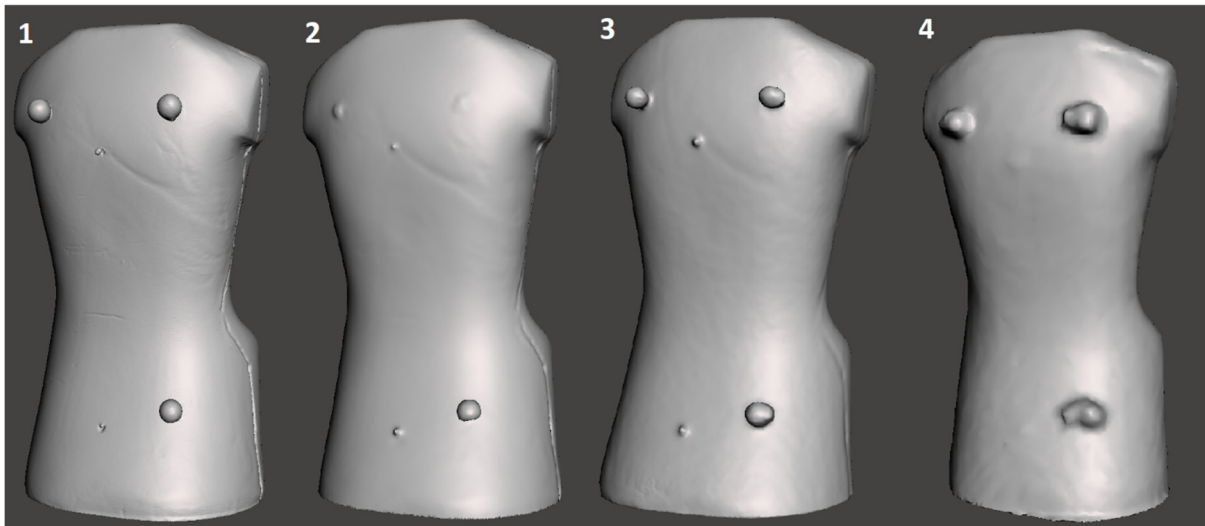
- Best fit (BEST)
- Best fit against several reference objects (REF)

The REF alignment has been chosen as the analysis method for the experiment, since it is the combination of BEST which allows the translation and rotation of the actual models to get minimal overall surface deviation and specifying reference objects for translation and rotation restriction. Also, the BEST method is not suitable for the alignment of models with significant deviations.

Model surface deviations with <1mm and <0,5mm surface coverage has been investigated.

3. Results

Three scans of the milled torso were taken with every device, or app, making a total of 12 3D models (figure 2). Every scan took approximately 30 seconds to make if the time of postprocessing is not considered and the whole process has been performed without any major errors.



*Fig. 2 3D scans acquired by different 3D scanners
(1 Artec Eva, 2 Creality CR-SCAN 01, 3 COMB, 4 3D Scanner app).*

The result of the actual to nominal model comparison with the REF method, with a <1mm surface coverage is shown in figure 3. The highest actual to nominal surface precision had the Creality CR-SCAN 01, with a 94% <1mm surface coverage, and a 75% <0,5mm surface coverage. The model acquired by the COMB app has significantly lower surface precision (32%) with <0,5mm surface coverage to the nominal model. Nevertheless, the surface precision with <1mm surface coverage to the nominal model is approximately 2 times higher (65%). The 3D Scanner App has the lowest surface precision with <1mm (44%), and <0,5mm (22%) surface coverage out of the 3 tested scanning systems. The percentual surface coverage is summarized in Table 1.

Table 1 Percentual surface coverage of individual models.

3D scanner	<1mm surface coverage [%]	<0,5mm surface coverage [%]
Creality	94	75
COMB	65	32
3D Scanner App	44	22

Best fit against several reference objects REF (1 mm)

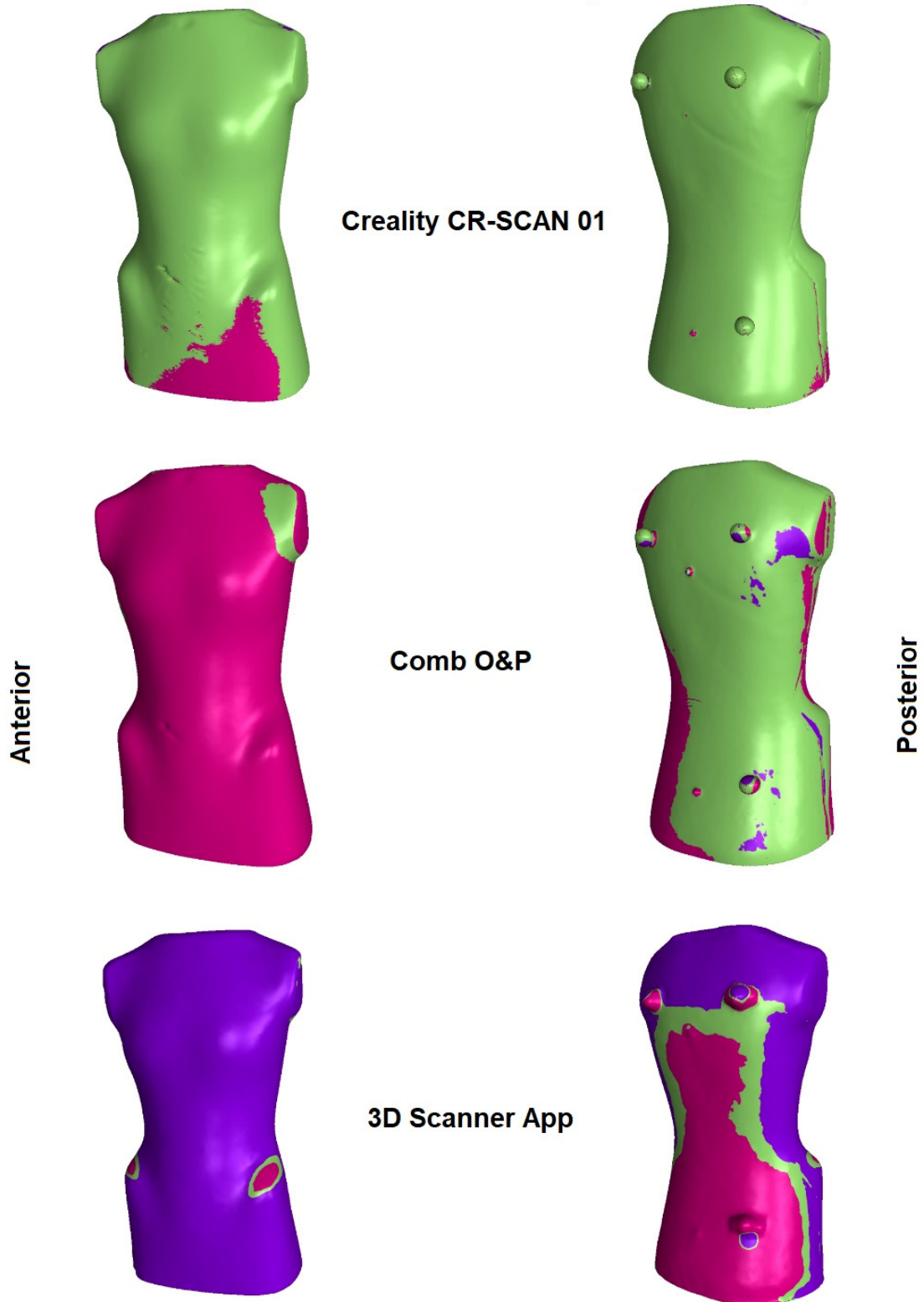


Fig. 3 Actual to nominal model comparison with the REF method, with a <1mm surface coverage in VGStudio MAX (green color – in range, pink color > +1mm, purple color < -1mm).

4. Discussion

When inspecting the acquired 3D models of different scanners, the Creality CR-SCAN 01 scanner had difficulties capturing the shape of the landmarks on the posterior side of the torso model (figure 4), even though it had the best recorded results regarding the surface precision. Even the free 3D Scanner App was able to obtain these landmarks, although the shape is deformed, and the surface is not that precise. Since the precision of the Creality scanner given by the manufacturer is 0,1mm and the resolution is 0,5mm, it should be able to capture these features. In future work, this should be investigated more thoroughly.

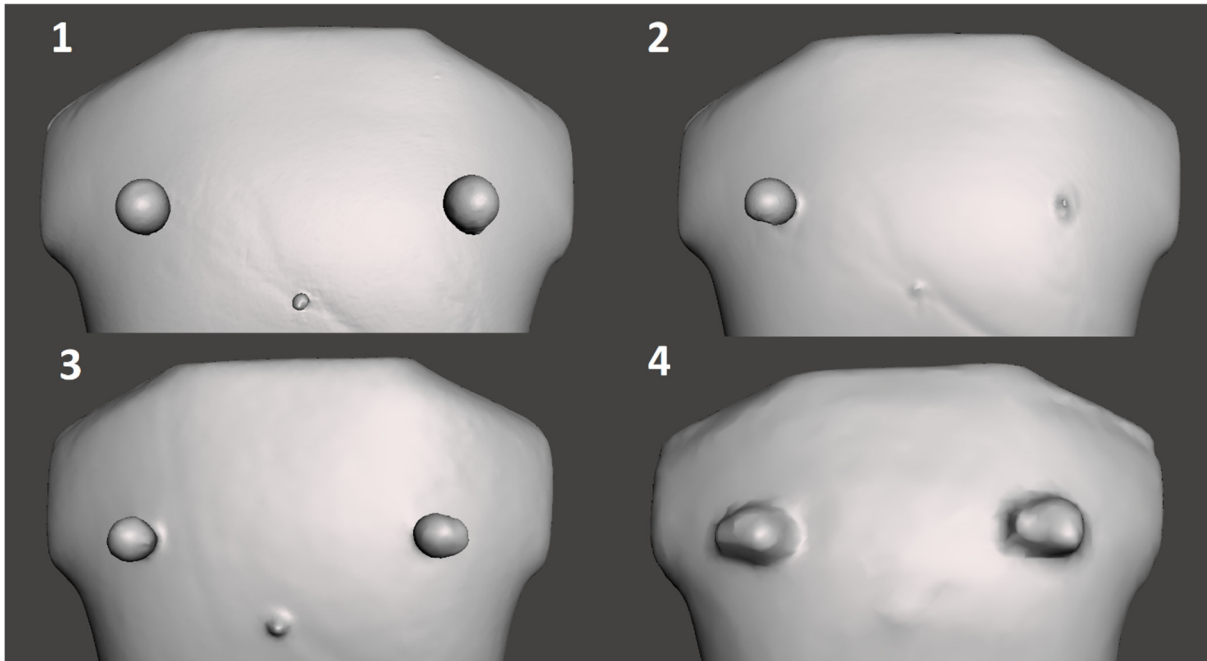


Fig. 4 The shape of the landmarks on the posterior side of the torso model acquired by different 3D scanners (1 Artec Eva, 2 Creality CR-SCAN 01, 3 COMB, 4 3D Scanner app).

From the results that have been obtained from the experiment it can be stated that 3D scanning using a smartphone/tablet and an appropriate scanning app can be used as a method for surface data obtainment for P&O purposes. It is advisable to use an app suitable for P&O development, because not all apps might have a high surface precision. In this experiment we used a paid, professional P&O app and a freely downloadable 3D scanning app, from which the free app had very low surface precision. 3D Scanner App had in some regions a deviation larger than 10mm, which in P&O practice is unacceptable (figure 5).

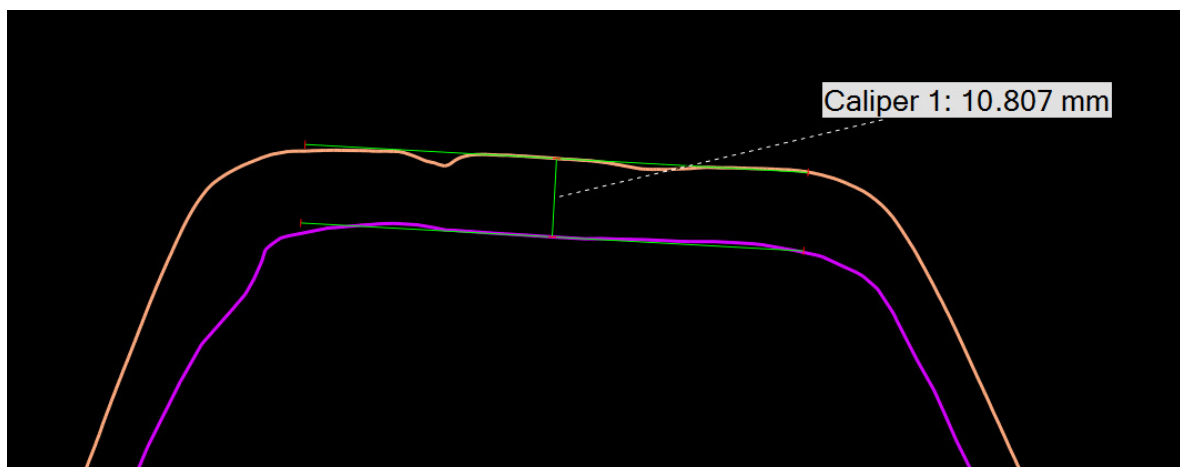


Fig. 5 Large deviation presented between the Artec Eva nominal model (red color) and the 3D Scanner App actual model (blue color).

Scanning with a smartphone, or in this case a tablet, has great advantage over conventional hand-held 3D scanners regarding the freedom of movement around the object that's being scanned. The disadvantage when using hand-held 3D scanners is that they need to be connected to a suitable computer via cable, which restricts the distance between the computer and the scanning object and limits the freedom of movement of the person scanning the object. This also makes the tablet more transferable and compact compared to a conventional hand-held 3D scanning system, which basically consists of a scanner, computer and sometimes an extension cord. Another benefit is that smartphone apps work not only as a scanner, but also as a data processing software so another computing device is not needed, and the acquired data is being automatically uploaded to a cloud, so no data storage unit is needed. On the other hand, data processing software for conventional 3D scanners have a large variety of functions and tools for 3D model processing and editing. Models of scans acquired by smartphone scanning usually need to be still processed in a suitable CAD software, before they can be used for prosthetic device development. However, some 3D scanning apps have the option to send the raw data directly to a clinic, where the prosthetic device will be developed.

5. Conclusion

In conclusion, a smartphone/tablet with a TrueDepth camera and a professional P&O app, like COMB, is an ideal solution for a CPO, because of all the benefits it has, regarding the surface precision, availability, compactness, and the simplicity of operation.

Future research includes comparing a larger number of 3D scanning apps, from which a lot of them work only with a Structure Sensor (Occipital, Inc., Boulder, USA) iPad adapter, which was not included in the proposed experiment.

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