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iPhone TrueDepth® cameras performance compared to optical 3D scanner for imaging the compressed breast shape

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ABSTRACT

Modelling of the breast surface shape under compression in the cranio-caudal and medio-lateral oblique views could advance the development of image processing techniques and of dosimetric estimates in digital mammography and digital breast tomosynthesis. Our goal is to compare the performance of a previously tested and used optical structured light scanning system (SLSS) capable of capturing the breast shape under compression to that of an infrared smartphone-based SLSS. Their performance was compared by scanning a cuboid phantom and two breast shaped phantoms (30 mm and 74 mm thick). Ten scans of the cuboid phantom were acquired with each scanner, and the measured length and thickness of the scanned shape were compared against the ground truth and between the two scanners. The performance of the scanners regarding breast-like phantoms was evaluated by calculating the maximum and mean distance, along with the root mean square difference, between each scanners result and against the matching ground truth. The cuboid phantom analysis showed a statistical difference for the thickness measurement in both scanners and in the length measurement for the optical scanner ($p<0.05$). However, no statistical difference was found between the scanner measurements. For the breast-like phantoms, the higher maximum distances were found in the infrared scans, but the mean distance between ground truth surface and the scans showed equivalent performance for both scanners. Our results suggest that the smartphone-based SLSS performance is sufficient to be used to create a complete three-dimensional model of the breast shape.

Key words: *structured light scanning system, smartphone, breast 3D modelling*

1. Description of Purpose

Improvement of image processing techniques and dosimetric estimates in digital mammography (DM) and digital breast tomosynthesis (DBT) could be achieved with availability of information on the actual breast shape. For this purpose, we have developed an accurate three-dimensional (3D) model of the compressed breast shape for cranio-caudal (CC) view DM and DBT acquisitions. However, developing a 3D model for the medio-lateral oblique (MLO) view of the breast is also necessary, since standard DM and DBT exams include both views.

In our previous work, a pair of optical structured light scanning systems (SLSS) (HP Inc., Palo Alto, CA, USA), each composed of a projector and two cameras, were used to record the breast shape in the CC view [1,2]. However, this system requires that the visible light emitted from the projector is reflected on the object and recorded by the cameras. If any interference occurs in the emitted light, the scanned object appears with gaps or artifacts. For the CC view, the breast support table and these optical scanners are kept parallel to the floor, and so the latter can be placed on both sides of the imaging system, at support table height, to scan the fully compressed breast. However, for the MLO view, the orientation of the support table, compression paddle, and compressed breast make an equivalent setup with the optical scanner challenging.

A surface scanner that could be placed closer to the DBT system would avoid the light interference problem faced by the optical scanner setup for the MLO view acquisition. Nowadays, a potential solution could be to use smartphones or even tablet cameras as 3D scanners. The TrueDepth® camera, present in the iPhone X and later versions (Apple Inc., Cupertino, CA, USA), is one such camera that makes use of this technology[3]. This camera uses the same principle seen in optical SLSS, but with infrared light. The post-processing of the infrared light reflected by the surface being scanned can be performed to create a depth map/3D scan of the targeted object that can be exported from the smartphone. Because of its ease of use and compactness, it is expected that this camera could be used for scanning the surface of patient breasts during

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MLO-view compressions. Therefore, the present study aims to evaluate this smartphone-based 3D infrared scanner performance, and compare it to that of the 3D optical scanner.

2. Methods

2.1 Scanning Setup

In this study, we evaluated the performance of both scanners with a DM/DBT system (MAMMOMAT Revelation, Siemens Healthineers, Erlangen, Germany) placed in a CC-view position since our previous work showed a good accuracy of the optical scanner in breast shape acquisitions with this setup[4].

An iPhone 11 with the integrated TrueDepth® camera was used. Based on the work from Verdaasdonk et al.[5], we selected the *Scandy Pro* application due to its claimed ability to provide a 3D resolution of 0.5 mm and because it enabled us to export scans as STL, OBJ, or PLY files.

The optical scanner was placed in a similar manner as reported in previous studies[1,2], i.e., with the set of two cameras and one projector placed on a tripod either to the left or right side of the DBT system. On the other hand, the new smartphone-based infrared scanner was placed closer to the compression paddle, as can be seen in Figure 1, due to its compactness and field of view characteristics[6].

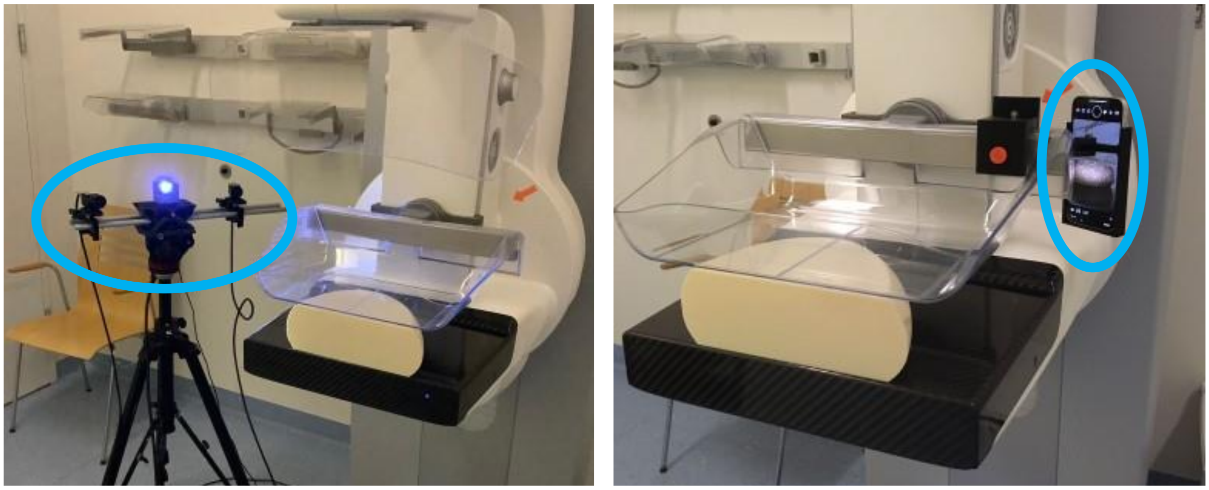

Figure 1: Scanning system setup: (left) optical scanner and (right) infrared scanner.

2.2 Scan Comparison

Three phantoms were used to compare the two surface scanning technologies (Figure 2): a rectangular cuboid phantom block of 50.2x50.2x10.2 mm^3 (LxWxT) and two breast shaped phantoms (small phantom: thickness = 30 mm, chest-to-nipple distance = 70 mm, length along chest-wall = 165 mm; large phantom: T = 74 mm, CND = 142 mm, LCW = 221 mm). The breast shaped phantoms were scanned with the compression paddle in place, while the cuboid phantom was scanned without the compression paddle. A set of 10 scans of the cuboid phantom was acquired with each scanner to evaluate the accuracy of the scanners compared to the ground truth and to each other. For this evaluation, both the length and thickness of the scanned object were measured in the images created by each scanning system.

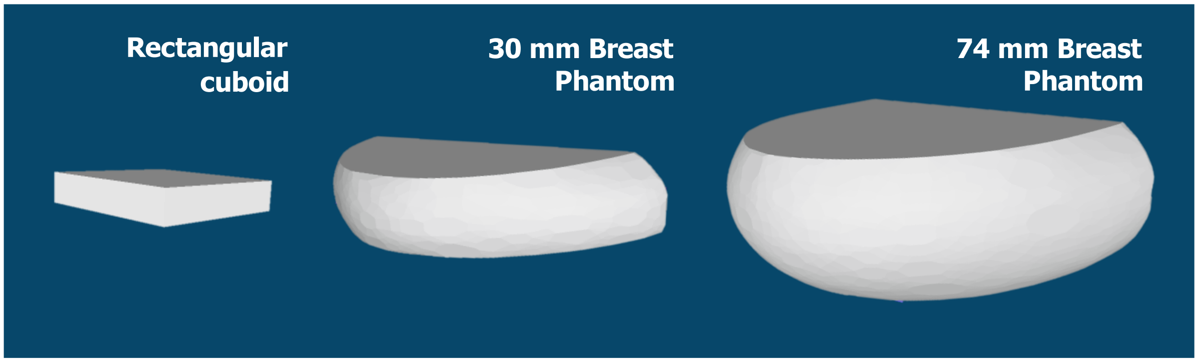

Figure 2: Ground Truth representation of phantoms used for surface scanning evaluation.

The comparisons were statistically evaluated by first performing a normality test on the measured metrics. Then, to test if the means were different, an independent sample t-test was applied. Finally, to compare the measurements of scanners to the ground truth in terms of thickness and length, a one sample t-test was used.

To assess the performance of the scanners in breast-like shaped phantoms, the scans of the anterior surfaces of the two breast shaped phantoms were compared to their respective ground truths. This was done by measuring the maximum and mean distance, along with the root mean square difference, between the resulting scan and the ground truth. For these measurements, the scans were first cleaned by removing background objects from the scanned point cloud. Additionally, the breast shaped phantoms were also aligned to the ground truth. Both steps were performed using MeshLab (Visual Computing Lab, ISTI - CNR, Pisa, Italy)[7].

3. Results

A statistically significant difference was found between the ground truth and both length and thickness of the optical scans while only a significant difference in the surface thickness was found in the infrared scans ($p<0.05$, see Table 1 and Figure 3). Additionally, the comparison between scanners revealed no significant difference for length or thickness measurements.

Table 1: Length and thickness measured for the cuboid phantom block.

Phantom test results	**Ground truth**	**Optical Scanner**		**Infrared Scanner**		**Optical vs Infrared**
		Measurement mean *(SD)* (n = 10)	**Scan vs. ground truth**	**Measurement mean *(SD)* (n = 10)**	**Scan vs. ground truth**	
Length (mm)	50.2	50.6 *(0.2)*	$P<10^{-3}$	50.3 *(0.5)*	P=0.50	P = 0.09
Thickness (mm)	10.2	9.5 *(0.1)*	$P<10^{-7}$	9.7 *(0.5)*	P=0.01	P = 0.26

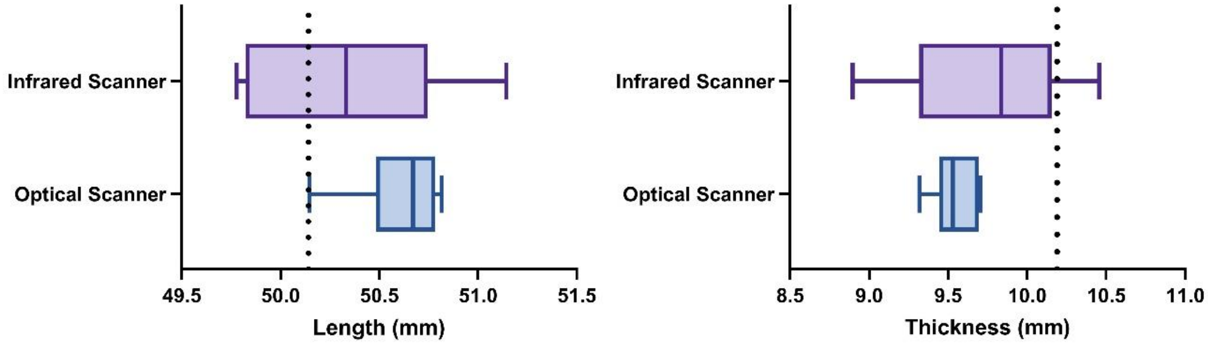

Figure 3: Box-plot for cuboid phantom measurements of length and thickness with the two types of scanners (dashed line shows ground truth dimensions of the phantom).

As can be seen in Table 2, the comparison between the breast phantom surfaces and their ground truth showed a higher maximum distance for the infrared scanner for the two breast shaped phantoms than that obtained with the optical scanner. Nonetheless, the mean distance between scans and ground truth presented similar results in the small and large phantoms. In Figure 4, we present an example of the deviations observed with both scanners in the large phantom when compared to its ground truth.

Table 2: Accuracy in the whole breast shaped phantom surface scans.

	Optical scanner		**Infrared scanner**	
Breast Phantom Size	**Small**	**Large**	**Small**	**Large**
Maximum Distance (mm)	2.41	3.31	4.85	8.58
Mean Distance (mm)	0.25	0.83	0.33	0.48
Root Mean Square (mm)	0.34	1.04	0.46	0.76

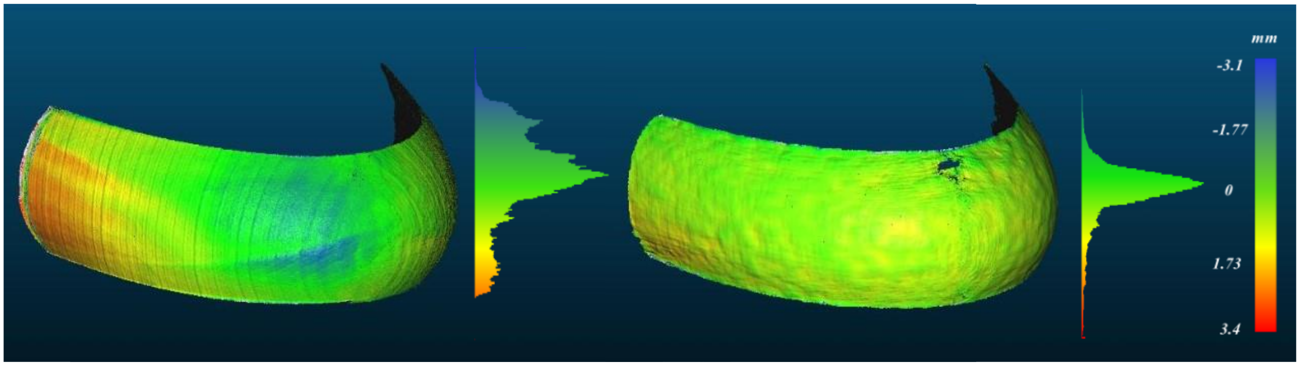

Figure 4: Distance from the ground truth map and histogram comparison of the (left) optical and (right) infrared scans of the large breast phantom. The same color scale is used for both maps.

New or breakthrough work to be presented

We present an evaluation of the accuracy of a smartphone-based 3D infrared scanner to record the compressed breast shape in digital mammography and digital breast tomosynthesis. The results indicate that the smartphone-based scanner can be used to create a complete 3D model of the breast shape.

4. Discussion and Conclusion

This work shows that the infrared and optical scanners have similar performance when compared to each other, with minor difference between scanners regarding the measurements performed on a cuboid phantom and a similar value for distance between breast shape surfaces.

Even though a statistically significant difference was found when comparing the scans with their ground truth for the cuboid phantom, we saw that this was true for both scanners, which failed to capture its real thickness, potentially due to its small size. The infrared scan did capture the phantom's true length correctly and obtained a comparable mean distance difference between scans and ground truth in breast shaped phantoms compared to the optical scans. Furthermore, although the maximum difference detected was higher, the overall scanned shape provided adequate 3D detail of the breast surface with the histogram comparison actually demonstrating a better performance for the infrared scanner. Therefore, we believe that the infrared scanner can be used for our future work of creating a 3D model of the compressed breast shape in the MLO view.

There are still some limitations to take into account when using the iPhone as a smartphone-based infrared scanner. Its positioning regarding distance to the object to be imaged and the angle at which the scan is performed are details that need to be taken into account[6]. Additionally, because the smartphone-based scanner is front-facing, it can be difficult to locate the target object to be scanned in the first attempt and some scanning distortions might appear on the top and bottom of the scans due to not scanning the targeted object in a parallel position. Designing the proper support to attach the scanner to the compression paddle should improve this and help setting the optimal position of the camera relative to breast. Nonetheless, this work is a first assessment of how well the smartphone-based infrared scanner can perform and based on the visual inspection of both phantoms scanned by each system, we could observe a good capture of phantoms' 3D shape.

The forthcoming implementation of a smartphone-based infrared scanner setup in the clinic, to record the MLO breast shape during our next study, should, of course, also take into consideration patient privacy during and after the recording. Therefore, the scanning and storage of the breast shape will be performed with the smartphone in flight mode, ensuring that the data collected remains in the device and can later be safely transferred through the internal hospital network.

In conclusion, the infrared scanner has the potential to be used as a practical, compact, and real-time processing 3D scanner to scan the 3D breast shape under compression for the CC and MLO view setup in DM and DBT acquisitions.

Credit Notice

TrueDepth® is a trademark of Apple Inc.

Disclosure

This work is an independent publication and has not been authorized, sponsored, or otherwise approved by Apple Inc. and has not been submitted elsewhere.

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