



Validation of the Kinect device as a new portable imaging system for three-dimensional breast assessment



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Summary *Aim:* The aim of this study was the evaluation of a new, simple, touchless, low-cost and portable three-dimensional (3D) measurement system for objective breast assessment.

Method: The Kinect Recording System by Microsoft was used. Coloured and depth images were captured of nine silicone breast implants of known volumes. The data were processed using Matlab[®] software. Volume measurements were obtained in a blinded calculation on the 3D images. For further comparison, implant volumes were assessed with the Arthur Morris device, a manual measurement tool.

Results: Four tests revealed that the true breast implant volumes were calculated within an error margin of 10%. Reproducibility of measurements was satisfactory. Overall, the accuracy and reproducibility of the measurements of the Kinect System were better than those of the Arthur Morris device. Accuracy of volume assessments with the Kinect System was satisfactory for clinical application. Our new portable 3D imaging system was successfully validated.

Discussion: The portable and easy-to-use system has several advantages against the currently available commercial systems. Despite a slight overestimation of the volume data, we felt that these results were very promising due to the repeatability of the measurements. After validating the measurement accuracy of the system in a simpler case, we aim to conduct further studies on 3D breast assessment.

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Conclusion: The results obtained with the Kinect System were sufficiently accurate and reproducible for application in 3D breast capture. We successfully validated the portable 3D imaging system for the first ever use in 3D breast assessment.

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Demands for audits and certifications of hospitals have increased in modern times. There is a need for planning and measurement tools in surgery to improve planning and assessment requirements in the health-care sector.⁹ For this purpose, objective quantitative and qualitative assessment methods are desirable.^{1,2}

To validate an assessment method, statistical tests are required.^{3,4} In 1986, a new statistical method for the assessment of a new measurement procedure was made public in the *Lancet*.¹ To evaluate a new method comparison with an established one was suggested. In case of absence of a method serving as a true and reliable standard, an agreement between the two methods should be investigated. This postulate was adhered to in our study. A comparison of the standard with a new method was drawn, and data as to the validity of the new method were obtained.

Among available objective assessment methods, there are those of three-dimensional (3D) imaging, involving outcome analysis by software calculations.^{2,8} Different 3D imaging systems show varying advantages and disadvantages, which need to be analysed before choosing the system for the required application. Computational demands of these systems are commonly high, and, in general, professional support for successful application and evaluation is necessary. One of the methods is multiple stereophotogrammetry, which offers various options for volume and shape analysis. However, the calibration procedure is cumbersome, as previously reported on a prototype system by Glasgow University.^{3,4} Furthermore, a monotone background and specific flash conditions are also necessary for a successful capture.

One of the possible applications of the method of multiple stereophotogrammetry is 3D breast assessment. To date, the 3D analysis of the breast is mostly restricted to the field of augmentation surgery. Several commercial systems have been introduced to the market to cater for this purpose. However, independent assessment of the validity of these systems for breast capture is still missing.

The 3D analysis of breast reconstruction is new.^{2,5} The aesthetic outcome has a significant impact on cancer survivors' quality of life.⁷

A quick, user-friendly, portable system at reasonable costs is desirable for the day-to-day plastic surgical practice in order to support planning purposes and surgical outcome analysis. Therefore, some preliminary tests with a new system have been conducted, carrying the potential to fulfil these needs.

Aim

We aim to investigate the possible usage of a simple, low-cost and portable 3D imaging system in a new application in the health-care sector.

Hardware

The Kinect Recording System by Microsoft, which to date has been used in the gaming industry, was independently tested for the first time in the field of breast assessment (Figure 1). The commercially available and portable camera comes reasonably priced for approximately 100 euros. Equipped with a natural user interface, it is designed to capture human motions within a living-room environment.^{6,11} The Kinect device has the size of approximately 30 cm × 7.5 cm × 6.4 cm ($w \times d \times h$) and the weight of approximately 1.4 kg. It is pre-calibrated and delivers a colour video stream with video graphics array (VGA) resolution (640 × 480 pixels) and an 11-bit depth stream, also in VGA resolution (640 × 480 pixels). Data can be recorded at approximately 30 frames per second. The Kinect has a measurement range of 0.8–3.5 m. The angular field of view is 57° horizontally and 43° vertically, and by using a motorised pivot it is possible to tilt the sensor up to 27° up or down. Since the depth accuracy is approximately 2 mm at a 1-m distance to up to 2.5 cm at a 3-m distance, the device is to be placed approximately 1 m in front of the patient. For additional information on the Kinect device, the Wikipedia entry <http://en.wikipedia.org/wiki/Kinect> is highly recommended.

Due to its low price, portability and the reasonable accuracy for indoor environments at close range, a software program has been developed to show the colour stream and depth stream from the Kinect device on a portable notebook computer in real time. A slider allows adjustment of the tilt of the Kinect and a record button can be used to save images, as well as the depth map, on a computer hard drive. Due to noise in depth values produced by the depth sensor, a patient is captured standing still in several



Figure 1 Kinect camera.



Figure 2 Kinect Recording System.

consequent frames. The standard setting is five frames. Then the depth values at each pixel are averaged over these frames to compensate for missing and inaccurate depth data and noise in measurements. The data are afterwards processed in Mathworks Matlab®, which is a programming language and an interactive environment for numerical calculus, visualisation and programming, in order to analyse and visualise volume.

Method

For quantitative evaluation of the accuracy when using the Kinect device, an experiment with silicone breast implants (of known volumes) was conducted. For this purpose, the portable system was adjusted on a tripod pointing downward for capture towards the surface of a table; the elevated position relative to the table is set to a distance of approximately 800 mm from the table surface (Figure 2). The Kinect recorder was attached via a Universal Serial Bus (USB) port to a laptop computer where two images of the object of interest were visible, one colour image and one depth image (Figure 3). After capture, a 3D reconstruction of the breast or area of interest was possible (Figure 4). The back surface of the implant was determined as planar surface by software calculation.

The best images were obtained when the implant was put on a flat, smooth table surface and repeated captures

at slightly different locations on the table were conducted. Nine silicone breast implants of different volumes were captured (Figure 5). To simulate natural conditions, implants of anatomical shapes of varying widths, lengths and projections were chosen. Images were repeatedly captured by the same examiner. 3D images were built (Figure 6) and volumes were calculated by computer scientists being ignorant of the actual volumes of the breast implants. Data were compared to those given by the manufacturers, which were considered to be the true volumes serving as the gold standard.

For comparison of the method, the breast implants were also examined with the Arthur Morris device to measure implant volume (Figure 7).¹⁰ The Arthur Morris device consists of a fixed, clear plastic tube and a stamp for breast volume measurements. For this purpose, nine silicone breast implants were inserted into the device in the best fitting way and measured in two consecutive tests.

Results

To validate the precision of the system and reproducibility of measurements, a series of experiments with nine breast implants with different volumes was conducted. To prove the reproducibility of the results, the volume measurements were conducted independently four times. In each experiment, the system showed slight volume over-estimation; however, the error did not exceed 10% of the ground truth volume in all experiments (Figure 8). The difference in measurements of the same object is attributed to the image noise and discretisation errors of the Kinect device. Therefore, reproducibility in this case shows that the measurement error does not exceed 10%. In this sense, the reproducibility of measurements was satisfactory. The test with the Arthur Morris device rendered that some implants were broader than the diameter of the fixed tube and some were smaller leading to obvious misfit and resulting discrepancy of the measurements from the true volumes. Some results matched surprisingly well and others were well outside the true measurements. The overall error rate exceeded 10%. Reproducibility of measurements was varying, while in five implants, the reproducibility of measurements was excellent, in the other four, it varied around 10% and sometimes more.

Overall, the accuracy and reproducibility of the measurements of the Kinect System were better than those of

Color Image



Depth Image



Figure 3 Double image with Kinect system, a color-photographic one and a depth image.

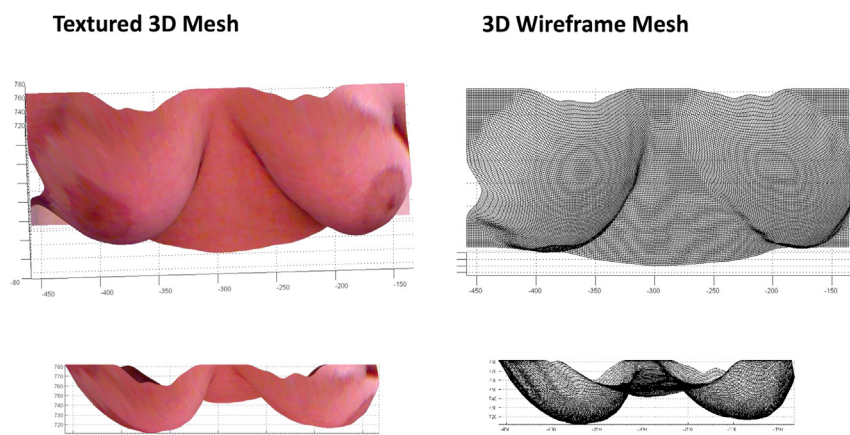


Figure 4 3D reconstruction of breast.



Figure 5 Range of 9 different silicone breast implants.

the Arthur Morris device (Table 1; Figure 8). In Figure 8, the ground truth (true implant volume data) is displayed on the x-axis and the measurements on the y-axis. The diagonal (continuous) line presents the ideal result and the dashed lines present the borders of the 10% deviation from the true measurements.

The accuracy of the volume measurements with the Kinect System was satisfactory for clinical application. Our new portable 3D imaging system was successfully validated.

Discussion

When validating the portable Kinect Recording System, we found data with an error of $<10\%$ from the true measurements. Assuming that a breast would be of 500 cc of volume, the error would be within a 50-cc aberration. To date, 50 cc was regarded as the amount of volume that might be visible with the human eye.¹² Therefore, we regard our results as satisfactory for clinical application, which lies in the 3D image-based documentation of the breast for the objective analysis of the existing breast volume and shape. Ultimately, we will be able to better plan surgical procedures and choose different techniques for different requirements such as different flaps for different volume and shape needs. The planning of implant sizes, for example, in mastectomy patients or patients with breast asymmetries will be facilitated. We will be able to visualise possible surgical results, to objectively measure and quantify these and assess if the surgical objective of the desired volume and shape has been achieved. Differences in accuracies of data in an *in vitro* model such as designed validation studies and clinical studies will be subject to future investigations. Error studies will help in this context and will need to be further developed.⁴ Objective data of surgical outcomes will be required for future audits and planning purposes. Since these were the first tests we conducted with this portable system, we felt that these results were inspiring regarding the ease of application. With the current study, we present the validation of a new system before going on to conduct a clinical study that will follow in a future

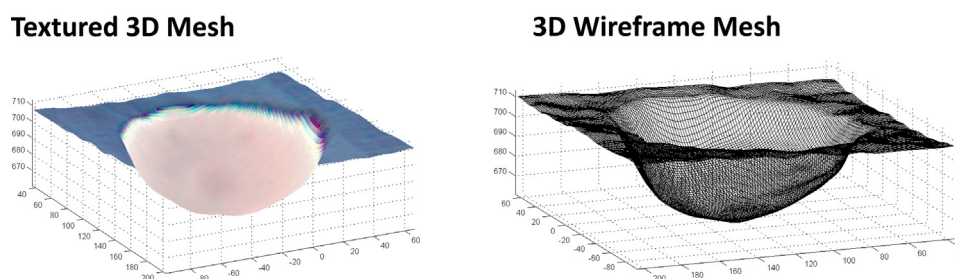


Figure 6 3D reconstruction of silicone breast implant.



Figure 7 Arthur Morris device for implant measurement.

publication. To give an outlook to what is intended to follow, some images obtained in real patients have been included in the current collections of images. However, the presentation of the prospectively designed clinical study would have been beyond the scope of this article.

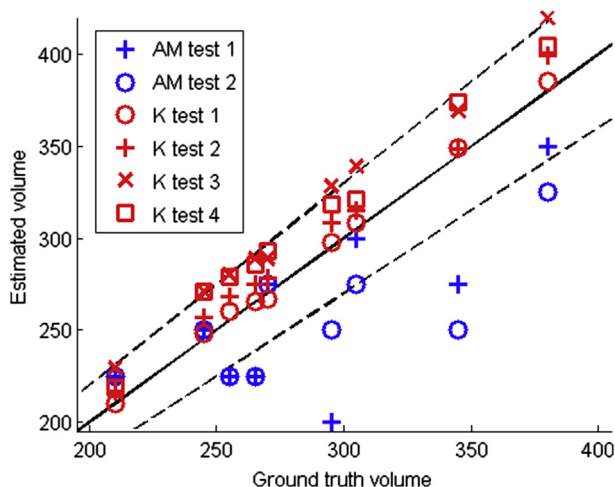


Figure 8 Graph of repeated data by Kinect system, (red points, different marker types correspond to the different experiments). Arthur Morris Device (blue points, different marker types correspond to different experiments). True volume data vs ground truth (continuous black line). 10% deviation from the ground truth (dotted black lines).

Table 1 Implant volume measurements repeated with Kinect System (column 1 till 4) repeated with Arthur Morris device (column 5 and 6) and true volume data = ground truth (column 7).

1	2	3	4	5	6	7
272	280	262	265	225	225	255
220	228	222	215	225	225	210
364	375	363	374	275	250	345
412	415	419	396	350	325	380
257	270	263	271	250	250	245
281	290	280	290	275	275	270
326	334	337	321	300	275	305
273	289	280	283	225	225	265
324	323	325	309	200	250	295

Traditionally, 3D imaging systems were built to capture either the face or the breast. While costly on one hand, systems were sold for clinical application without being independently validated.

By contrast, extensive efforts have been applied to validate a prototype 3D imaging system that had been previously described.^{3–5} Before conducting breast capture with this system, special attention to the calibration had to be paid. A calibration target object was used and was presented to the camera system at about 50 different angles. A calibration protocol by Glasgow University had to be followed. A blue background and four white studio flashes had to be used.

In comparison to these extensive efforts, the portable system, which was newly used in this research study, did not evoke the need for any calibration at all. No background or special flash demands occurred. From the perspective of a busy clinical doctor, this seems to be an immense advantage in the day-to-day application. Moreover, the system can be used in a restricted office environment. Nevertheless, determination of the correct capture distance with the Kinect System required some practice. Validation needs were met by independently assessing the accuracy and reproducibility of the procedure. The 3D capture as a 'no-touch technique' presents an advantage with respect to volume and shape assessment. The results were satisfactory even though, due to the portability of the system, standardisation of capture conditions is needed. Measurements on the captured images were enabled with the software supplied by computer scientist colleagues at Leibniz University, Hannover, Germany.

In the results obtained by blinded examination for comparison to the 3D measurements by application of the Arthur Morris device, it became obvious that for some implants, with the shape fitting the Arthur Morris device, the results were surprisingly good. However, when this was not the case, the measurements were way off the mark. In reality, there were two devices by Arthur Morris, built with plastic tubes of different diameters, to cater for slimmer and larger breasts. However, our study group only had access to one of the devices that was kindly provided by the developer some time ago. However, the overall results were less accurate than those with the Kinect System and less reproducible. The examination was the first ever

independent validation of the Arthur Morris device 35 years after the original publication. To date, however, the demands for accuracy and reproducibility have increased.

The Kinect Recording System with automated software measurements as a modern portable 3D imaging system has now shown its potential in the health-care sector for the first time ever and future studies are to follow. We plan to investigate possible applications in symmetry and shape analysis to estimate its potential for future day-to-day plastic surgical practice.

Conclusion

The Kinect System was sufficiently accurate and reproducible for the application in 3D breast capture. We successfully validated this portable 3D imaging system for a first ever use of 3D breast assessment. We expect this system to be available for clinical use in the future.

Conflict of interest

None.

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