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Validation of a passive stereophotogrammetry system for imaging of the breast: A geometric analysis

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ABSTRACT

The overall aim of this study was to assess the accuracy, reproducibility and stability of a high resolution passive stereophotogrammetry system to image a female mannequin torso, to validate measurements made on the textured virtual surface compared with those obtained using manual techniques and to develop an approach to make objective measurements of the female breast. 3D surface imaging was carried out on a textured female torso and measurements made in accordance with the system of mammometrics. Linear errors in measurements were less than 0.5 mm, system calibration produced errors of less than 1.0 mm over 94% over the surface and intra-rater reliability measured by ICC = 0.999. The mean difference between manual and digital curved surface distances was 1.36 mm with maximum and minimum differences of 3.15 mm and 0.02 mm, respectively. The stereophotogrammetry system has been demonstrated to perform accurately and reliably with specific reference to breast assessment.

1. Introduction

There have been continuing developments both in hardware and software in the clinical application of three-dimensional surface imaging techniques [1]. For example, non-contact and non-invasive techniques such as laser scanning and stereophotogrammetry have been applied to adults and for facial assessment [2,3]. Stereophotogrammetry has advantages for clinical applications as it provides high resolution colour information, called texture in computer science, overlaid onto a 3D surface mesh of polygons and is extremely fast. Typical shutter speed, with good lighting, is 20–50 ms and data reconstruction in the order of a few minutes. It uses pairs of conventional 2D digital photographs, for the Di3D system this is approximately 10–12 megabytes each, taken from two different viewpoints, and produces a 3D surface by matching corresponding points from the two images and calculating distances by trigonometry [2]. Currently, routine clinical applications of stereophotogrammetry include craniofacial and orthognathic surgical planning and outcome monitoring. More recently it has been recognised as a novel tool for breast assessment and a valuable adjunct to breast surgery in preoperative planning, postoperative evaluation and assessment of surgical outcome [4–8]. Tepper et al. introduced the concept of mammometrics, which they defined as 'the establishment of fixed planes and points to perform objective breast measurements' [9]. Sophisticated 3D software has been employed to measure parameters such as breast contour, size and position with an emphasis on developing standardised breast analysis, akin to cephalometrics in craniofacial surgery.

Breast cancer is the most common form of cancer among women with an estimated 1.38 million women diagnosed worldwide in 2008 [10], accounting for nearly a quarter (23%) of cancer cases [11]. The highest rates of breast cancer are found in Europe, where 332,000 new cases were diagnosed in 2008. In the UK there are approximately 125 women diagnosed per day and incidence rates have increased by around 50% over the last 25 years [10]. Initial treatment for breast cancer involves removing the cancer surgically, either by breast conservation followed by radiotherapy, or mastectomy which may be followed by immediate or delayed reconstruction. There are several reconstruction options, including the use of the patient's own tissue or prosthetic silicone implants to create a breast mound. Options include transverse rectus abdominis musculocutanous (TRAM) flap reconstruction which uses abdominal fat to recreate the breast and latissimus dorsi which uses tissue from the back. Implant reconstruction is the simplest surgical procedure with a shorter recovery time and avoids donor site wounds and potential complications [12]. TRAM flap reconstruction is considered to give the most natural texture and best symmetry. However there is a long and uncomfortable

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recovery, decrease in abdominal wall strength and extensive abdominal wall scarring. The ability to objectively compare different surgical reconstruction procedures, taking both the extent of surgery and aesthetics into account remains limited and there is not yet a routine standardised procedure for objectively assessing post surgical outcomes. Choice of procedure and post-operative analysis of shape, volume and overall symmetry is primarily subjective and relies heavily on the surgeon's perception and experience. Decisions about implant shape and size are based on simple linear measurements of the breast using a disposable measuring tape. Approximate estimation of breast of volume may be made from a model for half an ellipsoid, based on manual measurements [13].

Over the years, many techniques have been developed to perform objective assessments of the breast. More traditional, invasive techniques include direct anthropomorphic measurement, casting techniques and water displacement which can calculate distance measurements, surface area and volume with various degrees of accuracy [14,15]. Radiological techniques such as magnetic resonance imaging, X-ray mammography and ultrasound have been assessed [16–18]. These techniques are routinely used in diagnosis of breast cancer, although they are expensive, may involve the use of ionising radiation and are often not practical for routine assessment of morphology. 2D digital photography is currently widely used as a tool for patient communication and documentation of post-surgical outcome. However, the breast is a 3D structure and the morphological information that can be derived from these 2D pictures is limited. Measurements obtained from 3D surface imaging have the potential to be much more encompassing, are potentially more accurate and precise, and may enable previously unattainable measurements of breast parameters, such as volume, surface area, and asymmetry to be easily quantified. It also offers the advantage of instant image capture at a much reduced cost compared to radiological imaging modalitities as well as digital image analysis to enable quantitative evaluation over time.

A dedicated surface imaging system has previously been validated for imaging of the torso, where reliability, validity and precision were tested [19]. The authors demonstrated high reliability and accuracy of this system. We have adapted the Di3D system using wide-angle zoom lenses for acquisition of the torso for use in breast assessment for reconstruction surgery and patient communication (Di3D.com, Glasgow, United Kingdom). Reliability and stability of image capture, accuracy and repeatability of anatomical landmark placement and limitations of the stereophotogrammetry system must be investigated before the system can become an accepted tool for clinical research and be integrated into the hospital environment. The technical performance of the Di3D has previously been assessed for geometric accuracy, reproducibility and maximum field of view in capturing images of the face with a standard field of view using 50 mm lenses [20,21]. The overall aim of this study was to assess the accuracy, reproducibility and stability of this high resolution stereophotogrammetry system to image a female mannequin torso, to validate measurements made on the textured virtual surface compared with those obtained using manual techniques and to develop this approach to make objective measurements of the female breast.

2. Materials and methods

3D surfaces were acquired using the Di3D stereophotogrammetry system which consisted of two camera pods, each pod containing a pair of, 10.1 megapixel colour digital Canon EOS 1000D and a synchronised SunPak 383 Autoflash (Fig. 1). The system captures two stereo pairs of images and reconstructs the three-dimensional surface by matching data from each set of images (stored in JPEG format). The textured surface data consists of two parts. The three dimensional mesh, displayed in the Di3D system as four sided polygons. This approach is adopted as four sided polygons are simpler to display and it should be noted that they are not necessarily planar since they are made up of two triangles. The second part is the overlying full colour image derived from the original colour photographs.

Fig. 1. The Di3D stereophotogrammetry system including, dual pod head, blue screen background, calibration target and carrying cases.

The system was used to image a female mannequin torso made of polycarbonate. Red paint was applied in a speckle pattern to the surface of the mannequin to add texture as this aids the system software in performing image registration between the pairs of photographs to calculate depth. Stereophotogrammetry requires fine image detail at a pixel level to enable accurate distance calculation. A series of seventeen landmarks were marked with a fine point pencil, point diameter approximately 1.0 mm, distributed across the torso. The exact anatomical locations of these landmarks are listed in Table 1 and illustrated on a 3D image of the mannequin in Fig. 2. The camera system was calibrated using the manufacturers' calibration 40 mm target and system software Di3DView V5.2.4, in accordance with previously described method [21]. The calibration was deemed successful if the root-mean-square error was less than 0.5 mm, as defined by the manufacturer. Wide-angle zoom lenses (Tamron 18–55 mm, tamron.com, Saitama, Japan) replaced the standard 50 mm lenses supplied with the system, to ensure greater coverage of the mannequin. The mannequin was positioned facing the centre of the camera configuration at a distance of 90 cm and imaged using system settings recommended by the manufac-

Table 1
Anatomical landmarks on mannequin.

1, 2	Acromial extremity of clavicle
3	Suprasternal notch
4, 5	Anterior axillary fold
6, 7	Nipple
8, 11	Lateral point of inframammary fold
9, 10	Medial point of inframammary fold
12, 13	Inferior point of inframammary fold
14	Xiphoid process of sternum
15	Navel
16, 17	Anterior of the superior iliac spine