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3D surface-imaging for volumetric measurement in people with obesity

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Abstract

BACKGROUND: Current methods for tracking the progress of people with obesity towards a weight loss goal appear simple and potentially misleading. A technique to quantify change in body shape whilst visualising areas of the body where weight loss occurs would be advantageous, and has the potential to be used as a motivational tool. Three-dimensional (3D) surface-imaging would serve as a good basis for such a technique, however current systems are prohibitively expensive.

OBJECTIVE: Highlight the use of a cheaper alternative 3D surface-imaging system for volumetric measurement in people with obesity.

METHODS: A recently developed low-cost 3D surface-imaging system was used, having previously being validated in a healthy population. A total of 61 people with obesity, enrolled on a weight-loss programme, were surface-imaged using the system.

RESULTS: The findings suggest the low-cost system can obtain 3D surface-images of an obese human body, from which numerical parameters could be calculated and further analysis conducted.

CONCLUSIONS: Further studies will focus on the validity and reliability of such analyses and the potential of the system to be considered as a long-term instalment in primary healthcare settings as a weight loss aid.

Keywords: 3D Surface-imaging, Anthropometry, Obesity, Volume

BACKGROUND

Current methods to assess weight loss outcomes includes balance scales [1], tape measurement [1] or ‘before and after’ photographs [2]. These can mislead practitioners and patients, leading to inaccurate perceptions of effectiveness. For example, a patient may show no change in weight when stood on a balance scale, but may have lost weight from one area of the body whilst gaining weight elsewhere.

A measurement technique that enables change in body shape to be quantified, in addition to determining the areas of the body where change has occurred would enhance understanding of the impact and effectiveness of weight loss programmes. This technique would enable tracking of progress towards a weight loss goal, and could potentially be used as a motivational tool to encourage weight loss by enabling users to see how their body shape changes.

3D surface-imaging appears a suitable technique to measure body shape change. It reduces inaccuracies [3-4] inherent with current techniques, such as skin depression and soft tissue artefact [5] which is further exaggerated in people with obesity. 3D surface-imaging is less invasive than manual measurement and takes less time [6].

However, the majority of current 3D surface-imaging systems are prohibitively expensive (approximately £10,000) [7], require skilled operators, and involve lengthy post-processing of captured data. Wicke and Dumas [8] suggested structured light based systems would be a suitable low-cost alternative to current techniques. We have developed a low cost (~ £1,000) 3D surface-imaging system, comprising four pseudo structured light depth cameras (Microsoft Kinect®) capable of obtaining 3D surface-images of the human body in less than one second. However, thus far it has only been validated using a healthy weight population [9].

OBJECTIVE

The objective of this technical paper is to highlight the use of the system when surface-imaging people with obesity. Future studies will focus on the development of techniques to obtain numerical parameters from the 3D surface-images.

METHODS

The 3D Surface Imaging System

The surface imaging system comprised four Microsoft Kinect® sensors mounted in a vertical orientation. This increased the vertical field of view, and allowed the Kinects® to be positioned closer to the people being scanned, maximising scan resolution [10].

Initial investigations suggested a capture area of 0.8m x 0.8m was sufficient to contain the range of participants that may be scanned. Kinects were affixed to tripods, located 1.75m from the centre of the capture area and 1.27m from the ground. Figure 1 shows the scanning system positioned in the Rotherham Institute for Obesity (RIO).

[Insert Figure 1 here]

Custom software created using the Microsoft Kinect® software development kit (Microsoft Corporation, Redmond, USA) was used to control the Kinects, perform calibration, and capture images. The Kinect’s depth data can exhibit distortion, therefore each device was calibrated before first use [11].

The local coordinate system of each Kinect was aligned to a global frame, enabling capture of a single 3D model. A calibration object comprising four 120mm diameter spheres mounted on a vertical rod was placed in nine positions covering the capture volume. Point clouds and corresponding depth images were captured by each Kinect. A technique comprising image processing, rigid body transformation [12], and RANSAC point discrimination [13] was used to produce the transformation matrices to align each point cloud with one another.

The entire calibration process (including data collection and processing) took approximately nine minutes. Once calibrated, bespoke software was used to capture 3D surface-images rendered with colour. The Kinect's infra-red (IR) projectors were switched on and off during capture, preventing interference between neighbouring sensors [13], resulting in a data collection time of around 0.9 seconds.

Participants

After institutional ethical approval, 61 participants enrolled in RIO's programme were recruited. Participants read the information sheet and gave their consent. Inclusion criteria was a BMI > 30 kg/m^2 and able to stand unaided. Twenty-four of the participants were male, whilst thirty-seven were female. Other characteristics are summarised in Table 1.

[Insert Table 1 here]

Data Collection Protocol

Participants were asked to remove their shirt, total body mass was recorded using a body composition analyser (Tanita, Amsterdam, Netherlands) and stature recorded using a Leicester height measure (Invicta Group, Leicester, United Kingdom).

Participants were palpated and marked with six coloured circular markers, identifying anatomical points in the colour mapped point clouds. Anterior markers were placed on the xiphoid process and anterior superior iliac spine (ASIS). Posterior markers were placed over the spine at the same height as the anterior markers (Figure 2).

[Insert Figure 2 here]

Footprints were placed on the floor to ensure participants stood in the correct place during capture. The position and orientation of the footprints was designed to aid balance and reduce postural sway, improving scan reliability [9].

Participants were asked to adopt the ISO 20685-1 [14] scanning pose, with arms abducted by 20^{o} with respect to their trunk. However, this led to areas of the point cloud being occluded or merged together, owing to the size of participants' arms so the pose was adapted, to an abduction angle of 75^{o}. Hand supports (tripods) were used to limit involuntary movement during scanning by providing light touch stabilisation [15-16], and to assist reliably adopting the same position.

Participants were asked to hold their breath at the end of the expiration cycle (end-tidal expiration) throughout the imaging [6]. This ensured the diaphragm was empty, limiting shape change of the trunk between data capture, aiding reliability.

Three-point clouds of each participant were collected, with the participant leaving and re-entering the capture area between each collection. The field of view was restricted so that little more than the torso segment was included to ensure each participant was anonymised.

Results and Discussion

Each point cloud was visually inspected to determine data quality. Each point cloud successfully captured a 3D surface profile of the participant's torso segment (Figure 3).

[Insert Figure 3 here]

Point clouds of some participants were found to contain holes (Figure 4) around the spine and lower abdomen.

[Insert Figure 4 here]

Holes around the abdomen were caused by areas being occluded from the Kinects by excess or overhanging fat and skin. Holes around the spine were caused by participants having a more prominent surface profile to the left and right of their spine - due to their large body mass, occluding this area from the Kinect's view. This problem could be reduced by making the spinal area more prominent to one of the sensors but issues could arise in other areas of the body. Importantly, the physical size of such gaps in the surface were not a problem, and could be cleaned using available 3D hole filling algorithms and smoothing splines.

Difficulties were encountered when palpating and marking some participants. For example, it wasn't possible to accurately palpate and mark the ASIS points on participants with large amounts of overhanging fat and skin around the lower stomach, as bony landmarks weren't apparent. Excess fat and skin means the markers will likely move around between imaging, and are unlikely to accurately represent their intended points under the skin, impacting inter-scan reliability. Little can be done to adapt the land-marking protocol to reduce these problems in people with obesity.

It was not possible to use the ISO 20685-1 scanning pose, owing to the size of participants arms and overlap with the trunk. Given the increased abduction angle used in this study (75^o instead of 25^o), there is greater potential for movement of skin and tissue, potentially reducing inter-scan reliability. Hand supports are needed to ensure participants adopt the same scanning position over repeated scans.

Owing to reduced mobility and larger size of some participants, there was a greater likelihood of the system being knocked when participants entered and exited the scanning area. Therefore, the system was recalibrated between each participant. This was only a requirement due to Kinect® sensors being mounted on tripods which would not be necessary if the system was permanently installed.

Conclusion

Our low-cost 3D surface-imaging system can be used to capture 3D surface profiles of people with obesity, is the first attempt to do so, and we have developed a protocol to optimise inter-scan reliability and surface accuracy. Holes were found in the surface data of some participants, owing to their individual physique. However, these could be eliminated with simple post-processing techniques. Future studies should focus on extracting measurements from the 3D surface data, quantifying inter-scan reliability, and demonstrating feasibility of this measurement in primary healthcare settings. Research should also seek to assess suitability of the system for motivating and quantifying weight loss.

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Authors' contributions

SC, SF, DB and JW were involved in the conception and design of the study. SF and SC conducted the literature review. MC provided access to the participants. SC undertook the data collection. SC & JW analysed and interpreted the data. SC and SF drafted the manuscript. SC, SF, DB, MC and JW were involved in revising the manuscript and finalising the content of the manuscript. All authors read and approved the final manuscript.

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Table 1: Summary characteristics of participants (n = 61)

	Mean	Standard Deviation
Age (years)	46	14
Mass (kg)	114.2	24.3
Stature (m)	1.7	0.1
BMI (kg/m^2)	40.4	6.1

Figure Captions

Figure 1: Physical layout of the scanning system at the Rotherham Institute for Obesity.

Figure 2: Location of the anatomical markers. Five markers were attached: 1) Xiphoid process, 2) Left ASIS, 3) Right ASIS, 4) spine, at the height of the ASIS markers, 5) spine, at the height of the Xiphoid marker.

Figure 3: A typical 3D surface image from the system.

Figure 4: Holes in the returned 3D surface data.

Figure 1

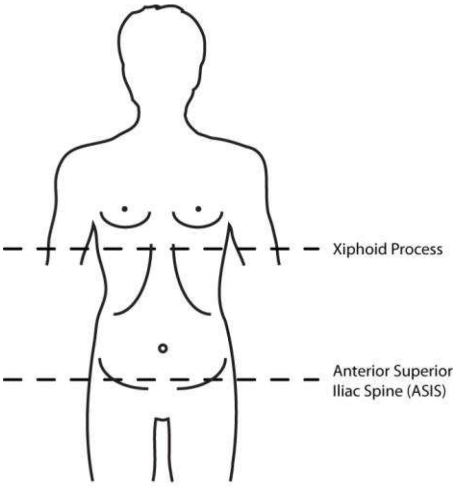

Figure 2

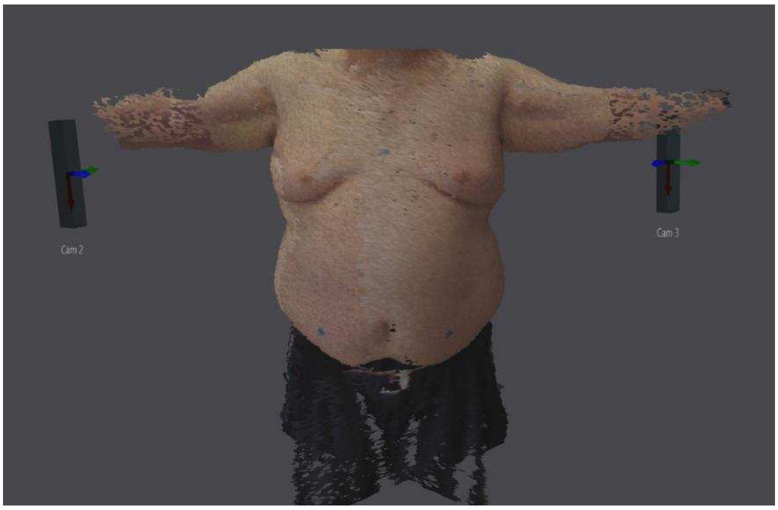

Figure 3

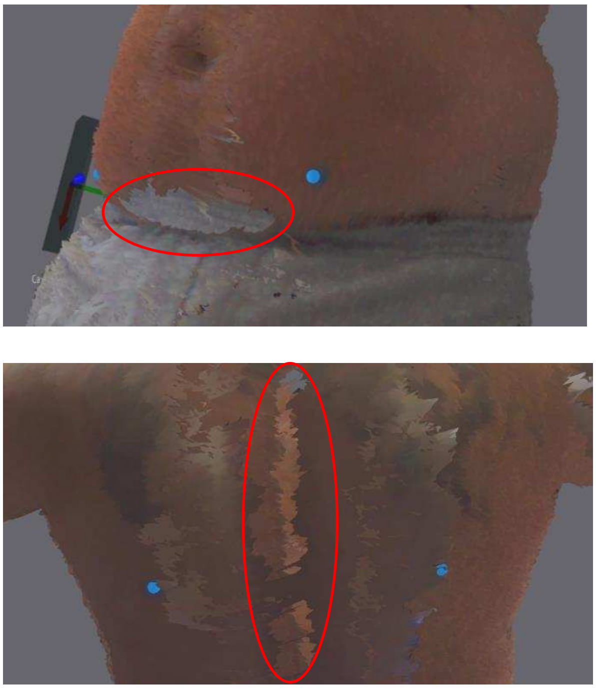

Figure 4