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IEEE Industry Connections (IEEE-IC) Landmarks and Measurement Standards Comparison in 3D Body-model Processing

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Contents

ABSTRACT 5

1. Introduction 5

2. The role of landmarks and measurements in 3DBP applications 7
   CAD clothing design 8
   CAD footwear design and fitting 8

3. Landscape of existing standards 9

4. Detailed comparison of preferred landmarks and measurements from use cases 11
   Required landmarks from use cases for full body 12
   Body regions 15
   Required digital landmarks from use cases for full body 16
   Digital body regions 19

5. Summary and recommendations 20

6. Citations 22

Appendix A Summary of content of 3DBP-related standards 24
   ISO 7250-1 (2017) 24
   ISO 8559-1 (2017) 24
   ISO 20685:2010 24
   ISO 20685-2:2015 25
   International Society for the Advancement of Kinanthropometry (ISAK) 25
   I-Ware Laboratory 25
   ISO/TS 19408:2015 25

Appendix B Landmarks and measurements from the existing standards 26
   Landmarks from all standards 26
   Measurements from all standards 28

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Abstract

This white paper reviews the current standards landscape for three-dimensional body scanning, body landmarking, and measuring. International standards are compared and recommendations are made for a minimal set of landmarks and measurements (L&M) needed for several industrial use cases of 3D Body Processing such as fit and size estimation, retail, clothing manufacturing, CAD tool developers, and body model storage and service.

1. Introduction

Human body structure is made up of 206 bones and 230 moveable and semi-movable joints in adults [1], and its outer body surface can range from an average of 2205 cm^2 at birth (50 cm, 3.5 kg) to 25,000 cm^2 for a 300 kg, 190.5 cm obese adult [19]. Three-dimensional (3D) scanners enable the fast, safe, and cost-effective acquisition of body surface geometry in 3D. Since their appearance, 3D models of the human body (or body parts) have been in use for various applications and are becoming ubiquitous in industries such as apparel manufacturing and retail. The increase in availability of body scanning equipment that are able to digitize body surface in combination with the expected proliferation of applications that use body models, justify efforts to standardize some of the interactions concerning 3D body models and associated data.

The 3D Body Processing (3DBP) initiative aims to improve interoperability between producers and consumers of 3D body models and associated services. In turn, standardization will ease the development of innovative solutions using body models and accelerate scaling of 3D body-model-based applications.

One of the common usages for 3D body models is the extraction of body measurements from the model since it is an efficient alternative to traditional anthropometry. These measurements are used in a range of applications such as ergonomic design, garment construction, mass customization, health or physical fitness. These measurements include distances, heights, widths, lengths, or girths. Measurements thus constitute an important metadata that should be kept along the 3D data processing pipeline, described in first white paper published by the 3DBP Industry Connections group [24].

In traditional anthropometry, human measurers locate the anatomical body references (designated as landmarks) by palpation of bony prominences. These landmarks are used as reference points when taking manual measurements (e.g., by measuring the distance between landmarks). Measurements are made using traditional tools such as calipers and measuring tape (Kouchi, et al. [17]). The digital extraction of measurements from a 3D body model relies on the same steps (i.e., landmarking and then measuring) but the definition of the landmarks is based on searches on the body surface geometry because no palpation is possible of the digital data. Some scanning solutions offer both the physical scan capture as well as a post-processing stage to calculate body measurements. In other cases, measuring software is offered as standalone software that accepts 3D body models from different scanners.

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Measurement definitions, postures, anatomical body references, instruments, procedures, and attire are standardized for different purposes (i.e., ergonomic design of products and environments, health and physical activity) by different independent organizations such as ISO[1], ISAK[2], IEC[3], CEN[4] or ASTM[5]. In garment construction, there are also definitions provided by the different patternmaking methods (Aldrich [1], Armstrong [3], Beazley [5]) However, there are discrepancies among measurement definitions leading to, for instance, different definitions for the same designations (e.g., waist girth). Even though body scanners are presented as alternative measuring instruments in the latest versions of standard (ISO 8559-1:2017 [9]; ISO 7250-1:2017 [8]), for these applications, definitions are still based on manually palpated landmarks and do not consider the particularities and advantages of the digital methods. This means that each measuring software developer creates a different interpretation and implementation of the same measurements and landmarks. To address this issue, new standards have been recently released providing body measurements, landmarks, body part and joint definitions from a natively digital perspective for digital fashion applications (ISO 18825-1:2016 [10], ISO 18825-2:2016 [11]). Despite the fact that these standards constitute an important step forward, these definitions are conceived to work with digital human models rather than with actual body scans of people. Additionally, none of the previously mentioned standards considers a procedure for defining new measurements, which is common practice among body scanner and measuring software suppliers.

Regarding quality, in the case of manual measurements, the skill of measurer strongly affects the reliability of manual measurements (Kouchi, et al. [17]); moreover, compatibility among manual measurements is often compromised due to systematic errors between differently skilled measurers. Analogously, in the case of digitally elicited measurements, the quality of the 3D scans has a strong influence on the reliability of measurements; moreover, the compatibility among digital measurements is often compromised due to differences in the interpretation and implementations of different measuring software.

The main benefit of 3D scanners is that they provide the whole surface of the body, i.e., 3D body model, which cannot be provided by traditional anthropometry. The accuracy of the raw scan point cloud (or surface) acquired by a body scan of a rigid object is also addressed by ISO 20685-2:2015 [12] and by proprietary procedures developed by manufacturers. However, it is not resolved for measuring living humans, which are soft and articulated. Moreover, the surface manipulations along the processing pipeline from the raw scan to the 3D body model is neither tracked nor quantified.

Within 3DBP initiative, the quality sub-group intends to provide methods, tools, benchmarks, resources, and testing procedures to define and quantify the quality of 3D models, as well as the quality of the critical metadata for use cases, such as body landmarks and measurements. Quality quantification is intended to be part of the quality-related metadata, which will provide complementary information about what the user receives and to what extent it is reliable, accurate, and trustworthy. Among the different steps within the 3D body processing pipeline (Figure 1), the sub-group is initially focused on (A) 3D scanning, (B) mesh surface reconstruction,

[1] International Standards Organization
[2] Internatoinal Society for the Advancement in Kinanthropometry
[3] International Electrotechnical Comission
[4] Commité Européen de Normalisation
[5] American Society for the Advancement in Kinanthropometry

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(C) digital landmarking, and (D) digital measuring since they are the more relevant for the considered use cases.

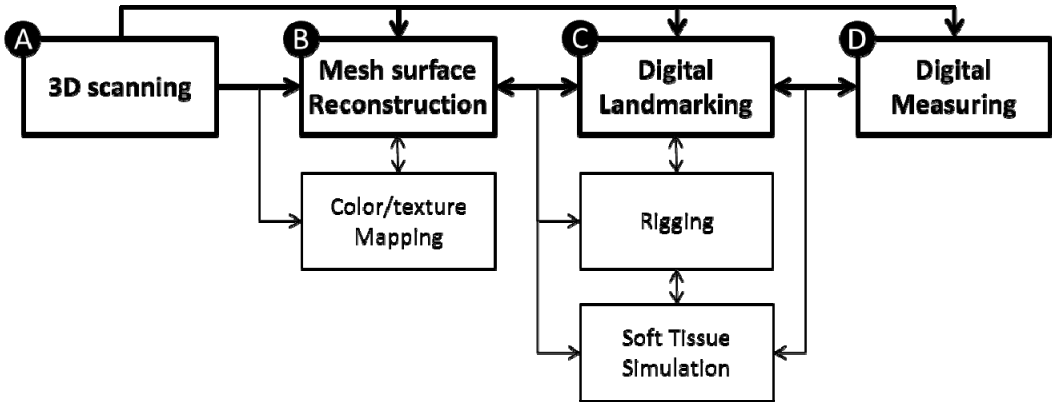


Figure 1 : 3D Body Data Processing Pipeline (McDonald [20])

Within these four processes, the quality attributes considered so far are related to the following:

- Descriptive information about the process, e.g., scanner supplier, scanner specifications, software version, scanning pose, or scanning attire.
- Qualitative descriptors and quantitative metrics for the processed 3D surfaces related to noise, artifacts, redundancies, holes, smoothing, and surface reconstruction.
- Reliability of body measuring software.
- Compatibility of digital body measuring and landmarking to methods dependent upon different digital software and/or traditional methods.

This white paper provides some examples of the role of measurements in 3DBP use cases as well as discusses the current landscape of standards related to body measurements and landmarks, and identifies the gaps not covered by them. Moreover, it provides a shortlist of measurements and landmarks that will be used within the initial use cases considered by 3DBP initiative; i.e., fit and size estimation, retail, clothing manufacturing, CAD tool developers, and body model storage and service.

2. The role of landmarks and measurements in 3DBP applications

As noted in the first paper published by the 3DBP Industry Connections group [24], there are different building blocks that can make up a 3DBP solution, such as the following:

a. Scanning or acquisition of the 3D surface data
b. 3D Model generation
c. Landmarks and measurements (L&M) identification
d. Digitization of objects (e.g., clothing, furniture)
e. Aggregation of data from various sources
f. Processing and integration of the data
g. Presentation/display/output the results

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An application may contain all or some of the previous building blocks. (Each of the blocks were described in detail in the first paper by the 3DBP group.) This paper focuses on landmarks and measurements (L&M) identification. Within this block, L&M are estimated by software that receives a body scan or a body model as an input. This software is not necessarily tightly coupled to the model generation step and can run on body models regardless of the scanner used to create them. Recognition and isolation of body parts may take place in this step as well. Some restrictions may apply. For example, the code may be expecting the subject to be scanned in a certain pose.

The following subsections give examples for how a 3DBP solution uses L&M. Implicit in the given examples is the understanding that certain landmarks and measurements must be provided with a model to make the use case possible.

CAD clothing design

The general procedure for constructing 3D garments with 3D-CAD software can be broken down into the following steps:

1. Create patterns in 2D space
2. Position 2D-patterns around the 3D-body (avatar)
3. Virtually stitch of the 3D-pattern
4. Simulate garment

In step 1, the accuracy of landmarks is of vital importance since 2D-patterns are being drafted based on the measurements/sizes of the target body to achieve a good fit. These measurements (body lengths and depths) are based on landmarks, whose maximum allowable error between extracted value and traditionally measured value should be within ±5 mm (ISO 20685:2010 [12]). Body circumferences should be within ± 4 mm to 9 mm.

In step 2, the landmarks on a 3D-avatar are used as reference locations for selecting arrangement points around a 3D-body. The accuracy of landmark placement is less important if the CAD software can drape clothing correctly over the avatar even when the initial positioning of the clothing is not that accurate. Note that this applies only to certain CAD software; some applications do require accurate landmark placement to provide good draping results.

CAD footwear design and fitting

Another example for the use of L&M is footwear fitting. The main concern is the positioning of the foot while being scanned to achieve appropriate information. The foot can be in a fully weighted state (standing with body weight on one foot, or full-weight bearing, FWB) or an unweighted state (sitting or with foot in the air; or non-weight bearing, NWB). ISO/TS 19408 [15] states that measurements should be taken in an evenly weighted position between the two feet (half weight bearing, HWB). However, that may not be the best position for all use cases in footwear, especially if the underside of the foot should not be compressed. The foot measurements maximum allowable error between extracted value and traditionally measured value should be within ±2 mm (ISO 20685:2010 [12]). This is in the same order of magnitude as the differences between the different weight-bearing conditions for different foot measurements, which can range from 3−7 mm depending on the measurement (Houston, et al. [6], Oladipo [21],Telfer and Woodburn [22], Tsung, et al. [23], Xiong, et al. [25]). Additional critical factors affecting L&M include the following:

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- Whether the foot is shod or unshod
- Whether the foot is fleshy or bony, i.e., soft tissue
- Whether the foot is wrapped, e.g., wearing a sock or in a cast
- Whether the arch of the foot is raised or flattened, i.e., the windlass mechanism

3D CAD software for footwear design is different from CAD software for clothing design as the whole process is based on the shoe last and not directly based on the human body. Shoe lasts are not the 3D representation of the ideal foot that fits the shoe, but rather a constructive component of shoe manufacturing. Shoe lasts are used to define the final shape of the shoes, are impacted by the intended usage of the shoes, and are directly related to shoe fit. The use of lasts for shoe development dictates two approaches for foot scanning. The foot is either scanned with the intent of creating a last for product development or creating a model of the foot for product fitting. Scanning to create a model for fitting is further complicated by the dynamic change in foot shape with flexing and movement.

The shape of the shoe is not based on static criteria. Foot dynamics, inner structure, and soft tissue wrapping/compression play an important role in shoe design and must be accounted for in the foot scan.

3. Landscape of existing standards

Independent organizations such as ISO, ASTM, and ISAK have already developed standards that are related to these topics, which cover partially the objectives of the 3DBP use cases. In particular:

- ISO 8559-1:2017 [9] and ASTM D5219-15 [4] provide body measurement designations and definitions for garment construction
- ISO 7250-1:2017 [4] provides body measurement designations definitions for ergonomic design
- ISAK [7] provides body measurement designations and definitions for shape tracking in health, sports and fitness
- ISO/TS 19408 [15] provides foot measurements designations and definitions
- ISO 18825-1 [10] and ISO 18825 2 [11] provide measurement and landmark definitions for virtual models used in fashion applications
- ISO 20685 [12] and ISO/DIS 20685-1 [13] provide 3D body scanning attire, compatibility thresholds between traditional and digital body measurements
- ISO 20685-2 [14] provides testing and reporting procedures for spatial quality of unanimated objects (sphere), as well as procedures for landmark repeatability of life-size human dummies and determination of hidden areas.

This white paper focuses on the differences and gaps of the landmarks and measurements mentioned in the standards shown in Figure 2 and Table 1. Any gaps in testing methods, thresholds, reference values, and test bench datasets may be addressed in future white papers.

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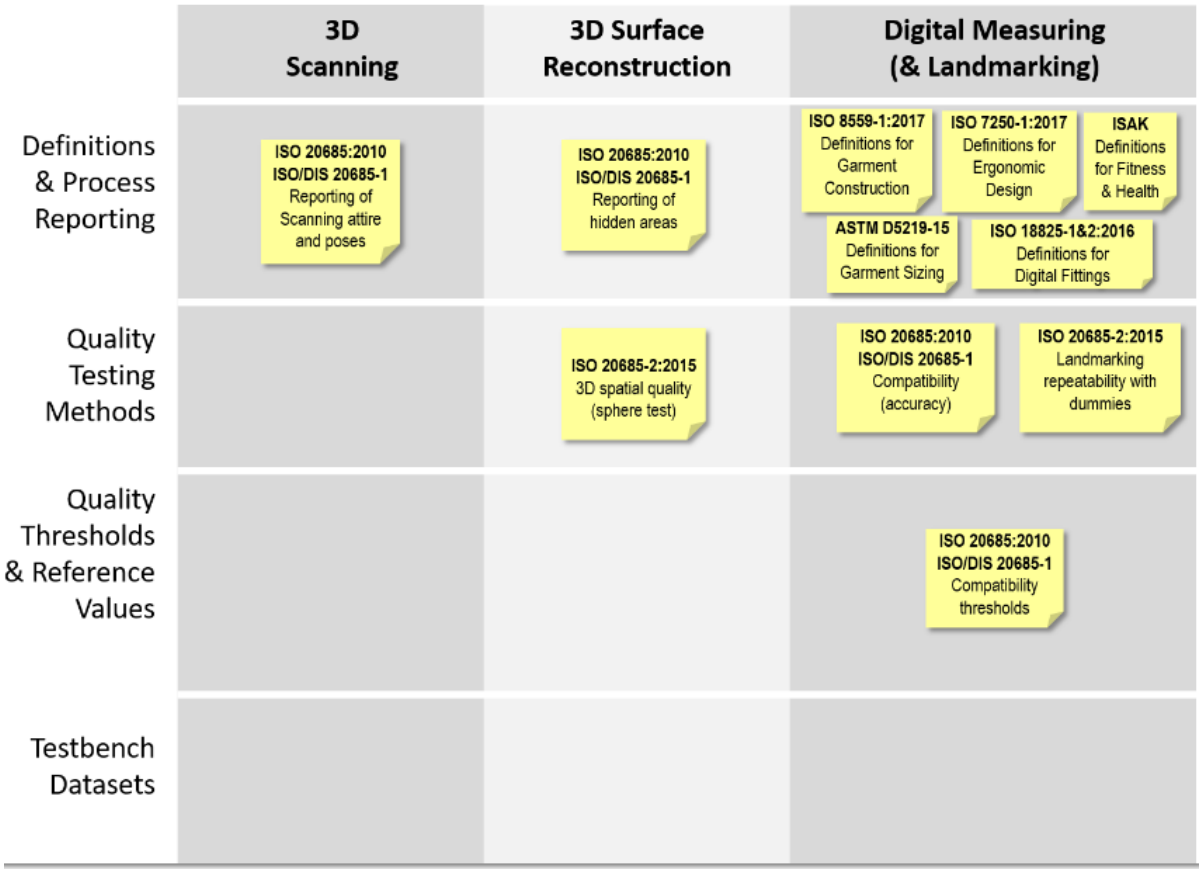


Figure 2 : Map of current coverage of existing standards and gaps to be covered by the Quality Sub-group, McDonald [20]

Table 1 : Lists of reviewed standards

ISO 8559-1:2017 and **ASTM D5219-15**	• Body measurement and landmarks definitions for garment construction (traditional perspective)
ISO 7250-1:2017	• Body measurement and landmark definitions for ergonomic design (traditional perspective)
ISAK	• Body measurement definitions for health, sports and fitness
ISO 18825-1:2016 and **ISO 18825-2:2016**	• Body measurement and landmark definitions for virtual models (digital perspective)
ISO 20685:2010 (ISO/DIS 20685-1)	• 3D body scanning attire • Compatibility thresholds between traditional and digital measurements
ISO 20685-2:2015	• Procedures for evaluating spatial accuracy of 3D body scanners • Procedures for landmarking repeatability of objects (life-size human dummies) • Reporting of hidden areas in 3D scanning of human bodies

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