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Ergonomics — 3-D scanning methodologies for internationally compatible anthropometric databases —

Part 2:
Evaluation protocol of surface shape and repeatability of relative landmark positions

Ergonomie — Méthodologies d'exploration tridimensionnelles pour les bases de données anthropométriques compatibles au plan international —

Partie 2: Protocole d'évaluation de la forme extérieure et de la répétabilité des positions relatives de repères

Reference number
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Foreword

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 3, *Anthropometry and biomechanics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 122, *Ergonomics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 20685-2:2015), which has been technically revised.

The main changes are as follows:

— landmark names in Table 1 and Table B.2 and subclause numbers in Table 1 harmonized with those in ISO 7250-1:2017;

— standard deviation of radial distances deleted from Clause 3;

— calculation of quality parameter for the repeatability of landmark positions, Annex B and Annex D revised.

A list of all parts in the ISO 20685 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Anthropometric measures are key to many International Standards. These measures can be gathered using a variety of instruments. An instrument with relatively new application to anthropometry is a three-dimensional (3-D) scanner. 3-D scanners generate a 3-D point cloud of the outside of the human body that can be used in a number of situations, including clothing and automotive design, engineering and medical applications. Recently, digital human models have been created from a 3-D point cloud and used for various applications related to technological design process. Quality control of scan-extracted anthropometric data is important since required quality can differ according to applications.

There are a number of different fundamental technologies that underlie commercially available systems. These include stereophotogrammetry, ultrasound and light (laser light, white light and infrared). Furthermore, the software that is available to process data from the scan varies in its methods. Additionally, methods to extract landmark positions differ between commercially available systems. In some systems, anthropometrists decide landmark locations and paste marker stickers, and scanner systems calculate locations of marker stickers and identify their names. In other systems, landmark positions are automatically calculated from the surface shape data. The quality of landmark locations has a significant effect on the quality of scan-extracted 1-D measurements, as well as digital human models created based on these landmarks.

As a result of differences in fundamental technology, hardware and software, the quality of body surface shape and landmark locations from several different systems can be different for the same individual. Since 3-D scanning can be used to gather these data, it was important to develop an International Standard that allows users of such systems, as well as users of scan-extracted measurements, to judge whether the 3-D system is adequate for these needs.

The intent of this document is to ensure the quality control process of body scanners, especially that of surface shape and locations of landmarks as specified by ISO 7250-1.

This document is not intended to be used for an acceptance test.

Ergonomics — 3-D scanning methodologies for internationally compatible anthropometric databases —

Part 2: Evaluation protocol of surface shape and repeatability of relative landmark positions

1 Scope

This document establishes protocols for testing of 3-D surface-scanning systems in the acquisition of human body shape data and measurements. It does not apply to instruments that measure the motion of individual landmarks.

While mainly concerned with whole-body scanners, this document is also applicable to body-segment scanners (head scanners, hand scanners, foot scanners). It applies to body scanners that measure the human body in a single view. When a hand-held scanner is evaluated, the human operator can contribute to the overall error. When systems are evaluated in which the participant is rotated, movement artefacts can be introduced; these can also contribute to the overall error. This document applies to the landmark positions determined by an anthropometrist. It does not apply to landmark positions automatically calculated by software from the point cloud.

The quality of surface shape of the human body and landmark positions is influenced by the performance of scanner systems and humans, including measurers and participants. This document addresses the performance of scanner systems by using artefacts rather than human participants as test objects.

Traditional instruments are required to be accurate to the millimetre. Their accuracy can be verified by comparing the instrument with a scale calibrated according to an international standard of length. To verify or specify the accuracy of body scanners, a calibrated test object with known form and size is used.

The intended audience is those who use 3-D body scanners to create 3-D anthropometric databases, the users of these data, and body scanner designers and manufacturers. This document intends to provide the basis for agreement on the performance of body scanners between scanner users and scanner providers as well as between 3-D anthropometric database providers and data users.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7250-1:2017, *Basic human body measurements for technological design — Part 1: Body measurement definitions and landmarks*

ISO 20685-1:2018, *3-D scanning methodologies for internationally compatible anthropometric databases — Part 1: Evaluation protocol for body dimensions extracted from 3-D body scans*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

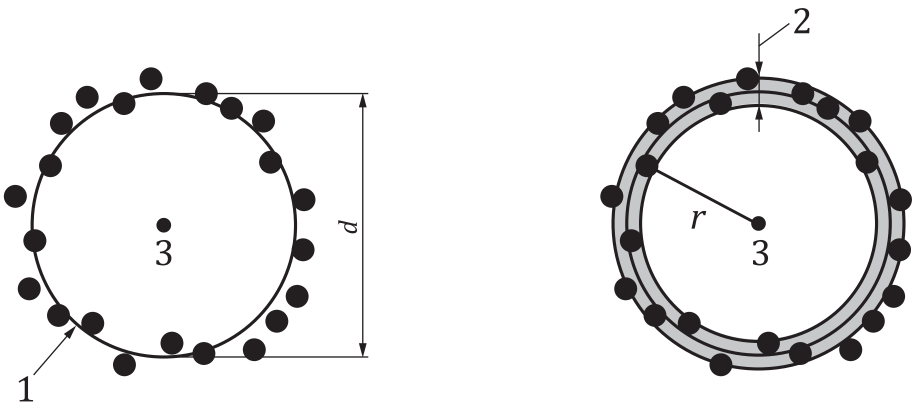
— IEC Electropedia: available at https://www.electropedia.org/

3.1
error of spherical form measurement
error within the range of the Gaussian radial distance, determined by a least-squares fit of measured data points on a test sphere

Note 1 to entry: Error of spherical form measurement is associated with the performance of the body scanner and the sphericity of the test sphere.

3.2
spherical form dispersion value (*n*)
smallest width of a spherical shell that includes *n* % of all the measured data points

Note 1 to entry: See Figure 1.



Key

1 best-fit sphere

2 spherical form dispersion value (*n*)

3 centre of the best-fit sphere

d diameter of the best-fit sphere

r radial distance of a measured data point from the centre of the best-fit sphere

NOTE 1 Best fit sphere is a sphere determined by a least-squares approximation of the measured points of the test sphere.

NOTE 2 Spherical form dispersion value (*n*), in which *n* % of the measured data points are located, is shown as the radial thickness of the shaded area of the right-hand image. Spherical form dispersion value (*n*) is calculated as the 100 – *n*/2 percentile value minus *n*/2 percentile value of the radial distances of the measured data points from the centre of the best-fit sphere.

Figure 1 — Error of diameter measurement and spherical form dispersion value

3.3
error of diameter measurement
error of the diameter of a least-squares fit of measured data points on a test sphere

Note 1 to entry: See Figure 1.

Note 2 to entry: See 4.3.2.

4 Test protocol for evaluating surface shape measurement

4.1 General aspects

The environmental conditions shall correspond to the operating conditions of the 3-D body scanner. When operation mode needs to be modified to measure the test object, it shall be specified in the report.

4.2 Test sphere

Spheres made of steel, ceramic or other suitable materials with a diffusely reflecting surface are used to determine the quality parameter spherical form dispersion value and error of diameter measurement. The diameter of the sphere should be close to the size of a part of the human body, such as the head.

The diameter and form of the test sphere shall be calibrated using precision measuring equipment such as a coordinate-measuring machine that has traceability to the international standard of the length; a calibration certificate shall be available.

The spherical form dispersion value (100) of the test sphere shall be smaller than 0,1 mm.

The surface properties of the test sphere can significantly affect the test results. The material of the test sphere shall be reported.

The reference sphere supplied with the body scanner for calibration purposes shall not be used for this test.

An example of a sphere is shown in Annex A.

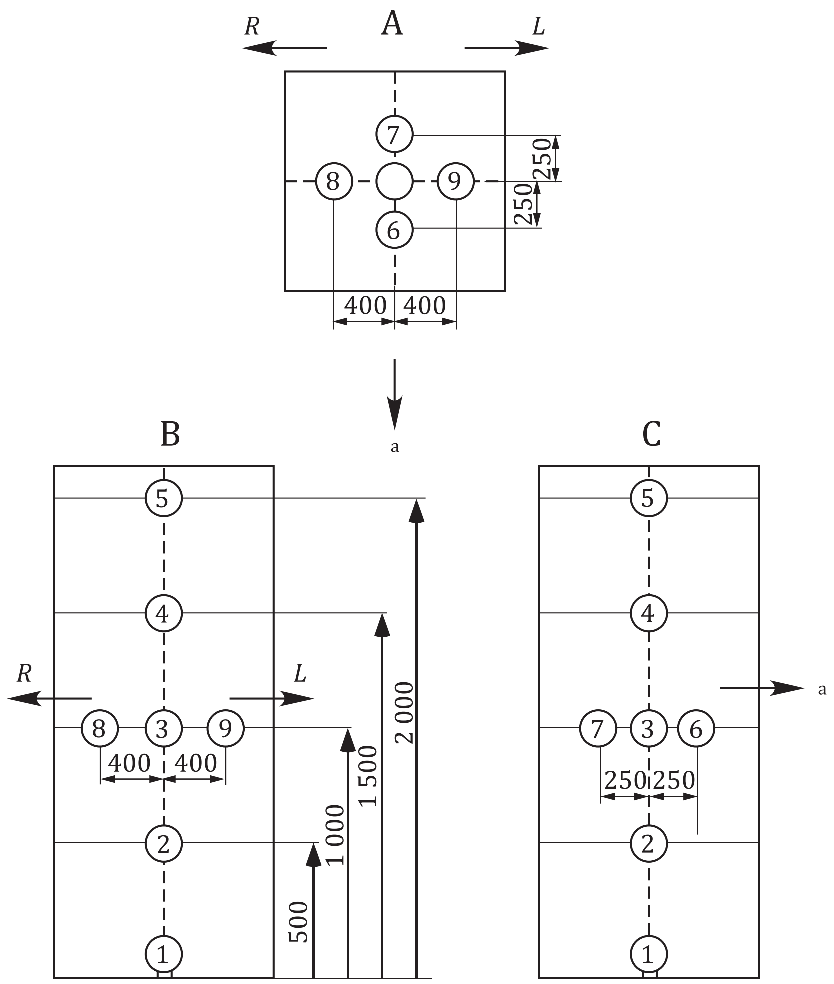
4.3 Procedure

4.3.1 Measurement of test sphere

The sphere shall be measured in at least nine different positions within the scanning volume. Measurement positions shall include the following nine positions (Figure 2): position 1 is the centre of the scanning volume on the floor; position 2 to position 5 are 500 mm, 1 000 mm, 1 500 mm and 2 000 mm off the floor, above position 1; position 6 and position 7 are 250 mm in front of or behind the centre position and 1 000 mm off the floor; position 8 and position 9 are 400 mm to the right or left of the centre position and 1 000 mm off the floor.

When the sphere cannot be measured in these positions due to a smaller scanning volume, measure the sphere at a position close to the intended position and record the exact position.

Dimensions in mm



Key

A top view
B front view
C right-side view
L left
R right
[a] Anterior.

Figure 2 — Measurement positions of the sphere

4.3.2 Calculation of quality parameters

Data points from objects other than the test sphere, such as a tripod, shall be deleted manually. Outlying data points due to reflection can also be removed.

The best-fit sphere shall be calculated from the measured data points. Calculate radial distances from the centre of the best-fit sphere to all data points.

Error of diameter measurement shall be calculated as the diameter of the best-fit sphere minus the calibrated diameter.

Spherical form dispersion value (90) shall be calculated as 95 percentile value minus 5 percentile value of the radial distances.

The standard deviation of radial distances from all the measured data points to the centre of the best fit sphere shall be calculated. This is an indicator of error of spherical form measurement and highly correlated with error of spherical form dispersion value (90)

4.3.3 Report

Material and calibration results of the test sphere [diameter and spherical from dispersion value (100)] shall be reported.

For each position, actual measurement position, error of diameter measurement, spherical form dispersion value (90) and standard deviation of radial distances from measured data points and the best-fit sphere shall be reported at least to the nearest 0,1 mm. Figures for measured data points of the test sphere can help with interpreting results.

Examples of the test procedure and report are shown in Annex B, Clause B.1.

5 Test protocol for evaluating repeatability of landmark positions

5.1 General aspects

The environmental conditions shall correspond to the operating conditions of the 3-D body scanner. When operation mode needs to be modified to measure the test object, it shall be specified in the report.

5.2 Test object

An anthropomorphic dummy representing the size and shape of a natural human, rather than an idealized human, shall be used. The dummy should have no movable parts and the posture should be that recommended in ISO 20685-1 for circumferences. It should be made of fibre-reinforced plastics (FRP), metal or other suitable materials with a diffuse reflecting surface. The landmarks to be evaluated shall be premarked on the dummy.

Landmark positions on the dummy should be determined by an experienced anthropometrist as described in ISO/TR 7250-4[1)] when the dummy is not premarked. If the physical representation of the 3D scan of an actual human is used, actual landmark positions shall be used.

An example of a dummy is shown in Annex A.

5.3 Landmarks

Landmarks to be evaluated are listed in Table 1. Among the 47 landmarks, No 1 to No 15 and No 18 to No 25, as defined in ISO 7250-1, and No 26 and No 27, as defined in ISO 20685-1, shall be evaluated. Landmarks No 16, No 17 and No 28 to No 47 are optional. When landmarks other than those listed in Table 1 need to be evaluated, these landmarks are numbered from No 48.

Before measurement, marker stickers are pasted on landmark positions to be evaluated. Marker stickers should be chosen to be appropriate for the scanner being tested.

Table 1 — Landmarks to be evaluated

No	Landmark	Source
1	Vertex (top of head)	ISO 7250-1:2017, 5.22
2	Tragion, right	ISO 7250-1:2017, 5.20
3	Tragion, left	ISO 7250-1:2017, 5.20
4	Orbitale – Infraorbitale, right	ISO 7250-1:2017, 5.13
5	Orbitale – Infraorbitale, left	ISO 7250-1:2017, 5.13

1) Under preparation. Stage at the time of publication: ISO/DTR 7250-4:2023.

Table 1 *(continued)*

No	Landmark	Source
6	Glabella	ISO 7250-1:2017, 5.6
7	Sellion	ISO 7250-1:2017, 5.15
8	Menton	ISO 7250-1:2017, 5.9
9	Opisthocranion	ISO 7250-1:2017, 5.14
10	Cervicale	ISO 7250-1:2017, 5.3
11	Acromion, right	ISO 7250-1:2017, 5.2
12	Acromion, left	ISO 7250-1:2017, 5.2
13	Mesosternale	ISO 7250-1:2017, 5.10
14	Thelion, right	ISO 7250-1:2017, 5.18
15	Thelion, left	ISO 7250-1:2017, 5.18
16	Iliocristale, right	Optional
17	Iliocristale, left	Optional
18	Iliospinale anterius – Anterior superior iliac spine, right	ISO 7250-1:2017, 5.7
19	Iliospinale anterius – Anterior superior iliac spine, left	ISO 7250-1:2017, 5.7
20	Stylion (radial stuylion), right	ISO 7250-1:2017, 5.16
21	Stylion (radial stuylion), left	ISO 7250-1:2017, 5.16
22	Ulnar stylion, right	ISO 7250-1:2017, 5.21
23	Ulnar stylion, left	ISO 7250-1:2017, 5.21
24	Tibiale, right	ISO 7250-1:2017, 5.19
25	Tibiale, left	ISO 7250-1:2017, 5.19
26	Lateral malleolus, right	ISO 20685-1:2018, 3.8
27	Lateral malleolus, left	ISO 20685-1:2018, 3.8
28	Suprapatella, standing, right	Optional
29	Suprapatella, standing, left	Optional
30	Neck shoulder point, right	Optional
31	Neck shoulder point, left	Optional
32	Front neck point	Optional
33	Anterior axilla point, right	Optional
34	Anterior axilla point, left	Optional
35	Posterior axilla point, right	Optional
36	Posterior axilla point, left	Optional
37	Omphalion	Optional
38	Trochanterion, right	Optional
39	Trochanterion, left	Optional
40	Buttock point, right	Optional
41	Buttock point, left	Optional
42	Radiale, right	Optional
43	Radiale, left	Optional
44	Mid patella, right	Optional
45	Mid patella, left	Optional
46	Sphyrion, right	Optional
47	Sphyrion, left	Optional

5.4 Procedure

5.4.1 Measurement

The dummy shall be scanned 10 times. After each scan, the dummy shall be moved slightly to simulate the variation in the standing position of human participants. Variation in position shall include antero-posterior and lateral translations and rotational differences. The 10 positions shown in Table 2 are recommended.

Table 2 — Recommended positions in which to scan the dummy

No	Position
1	The base position, the position where human participants stand
2	10 mm anterior to the base position
3	10 mm posterior to the base position
4	10 mm right of the base position
5	10 mm left of the base position
6	Rotate counter-clockwise: place only the right heel anterior to the base position by 10 mm
7	Rotate clockwise: place only the left heel anterior to the base position by 10 mm
8	10 mm anterior to the base position and rotate counter-clockwise as position 6
9	10 mm posterior to the base position and rotate clockwise as position 7
10	The base position

5.4.2 Calculation of quality parameter

Landmark coordinates are obtained for each scan using the available method.

Only those landmarks that can be obtained from all 10 scans shall be used to calculate quality parameters. The 10 sets of landmark position data are superimposed. After the superimposition, the error is calculated as the distance between corresponding landmark coordinates of two superimposed scans. For each landmark, the error is calculated for all pairs of superimposed scans, and mean error and standard deviation of errors shall be calculated as the quality parameters.

Annex D explains methods of superimposition of landmark data obtained from 10 scans and calculation of quality parameters.

5.4.3 Report

Material, size, posture, colour and other relevant information relating to the anthropomorphic dummy used shall be described.

For each landmark, the number of scans for which the landmark position can be calculated shall be reported. For the landmarks with 10 scans, mean error and standard deviation of errors shall be reported to the nearest 0,1 mm.

Examples of the test procedure and report are shown in Annex B, Clause B.2.

6 Evaluation of hidden area

6.1 General aspect

There are several aspects of quality of human body shape data that cannot be evaluated using a dummy, because dummies possibly do not represent the population of interest and the available body shapes are limited. One of the most important aspects that affects the quality of surface shape and landmark positions is the hidden area, a part of the body that cannot be measured because of the occlusion by other part(s) of the body. Hidden area depends on the body shape. Therefore, actual humans should be used to evaluate the hidden area as well as to verify that the scanner can accommodate the population of interest.

6.2 Recruitment of participants

Scans from more than one participant shall be used. Participants should represent the shape variability of the population of interest. This could include a combination of male and female participants who are small (e.g. 5th percentile) and large (e.g. 95th percentile) in stature and body mass index (BMI) or it could include people with various disabilities.

6.3 Posture control and measurement

The participant shall take the posture for circumference measurement recommended in ISO 20685-1. The participant is scanned once according to the usual scanning procedure.

6.4 Procedure to evaluate the hidden area

Measured data after ordinal data processing of the body scanner system should be displayed as the surface polygon without smooth shading. Some body scanners automatically fill gaps or holes before visualization. If possible, do not use such functions. If this is impossible, report it.

The operator checks the lack of surface data as the hidden area by eye inspection. The standard area code of the hidden area should be recorded. Table 3 shows the area codes. Other areas can be added when necessary.

Table 3 — Recommended positions in which to scan the dummy

Code number	Area
10	Top of the head
11	Under the nose
12	Back of the ear
13	Pupil
14	Under the chin
20	Over the shoulder
21	Armpit and the trunk
22	Under the bust
23	Under the buttocks
24	Under the crotch and the medial side of the thighs
25	Side of the body, arms and legs
30	Trunk side of the arm
40	The plantar part of the foot

6.5 Report

Mean, minimum and maximum values of body height, body mass and BMI of the participants shall be reported. The number of participants with hidden areas for each area shall be reported. Images of gaps or holes help with interpreting results.

An example of a report is shown in Annex C.

Annex A
(informative)

Sample of test object

A.1 Sphere

Figure A.1 shows a sample sphere made of hollow steel with TiN coating. It was calibrated using a coordinate measuring machine. The diameter is 120,015 93 mm and the spherical form dispersion value (100) is 0,018 96 mm.

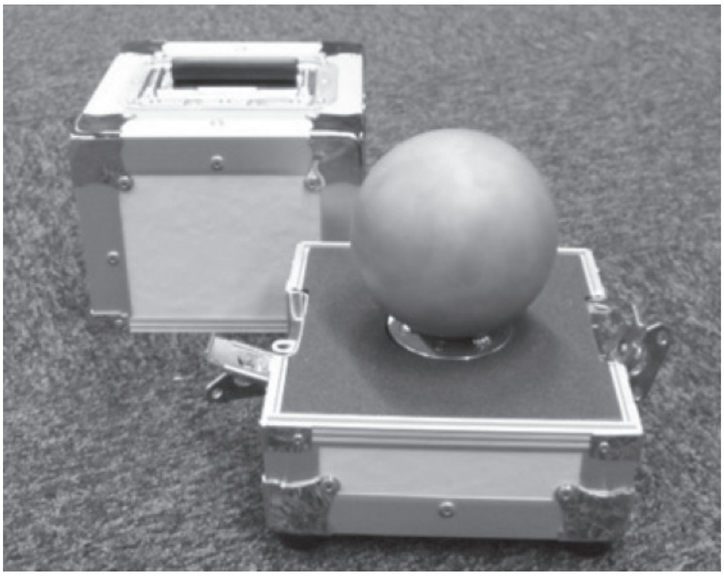


Figure A.1 — Sample sphere

A.2 Dummy

The sample anthropomorphic dummy shown in Figure A.2 is made of FRP. It has the mean body dimensions of Japanese women in their 20s. Landmark positions are marked with small dents. It takes the posture for circumference measurements as recommended in ISO 20685-1.

Figure A.2 — Sample anthropomorphic dummy

Annex B
(informative)

Example of test and report

B.1 Evaluation of shape measurement

B.1.1 General

A whole-body scanner was evaluated according to the protocol described in this document.

B.1.2 Test object

The test sphere shown in Figure A.1 was used. The material was steel. The surface was blasted and TiN treated. Surface colour was mat gold. The test sphere was calibrated in the National Metrology Institute of Japan. The diameter was 120,015 93 mm. The spherical form dispersion value (100) calculated as the difference between the maximum and minimum radial distances was 0,018 96 mm.

B.1.3 Procedure

The sphere was measured at positions 1 to 4 and 6 to 9. Since the height of the scanning volume was too small to measure the sphere at position 5, the sphere was measured at the height of 1 900 mm instead of 2 000 mm.

Best-fit sphere was calculated for the measured point cloud at each position after removing data points not belonging to the sphere. Software developed for this purpose was used. Error of diameter measurement, spherical form dispersion value and standard deviation of radial distances were calculated.

B.1.4 Report

Results are shown in Table B.1 as a report. These results are part of an interlaboratory test of body scanners using the same test objects. Evaluation results of three whole body scanners, including the one in this report, are published in Reference [2].

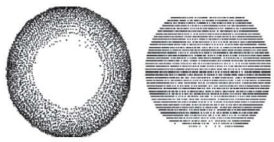
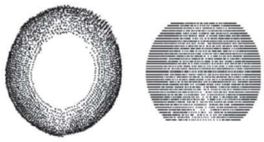
Results show that the accuracy is not uniform within the scanning volume. Error of diameter measurement is largest in position 4, while spherical form dispersion value (90) is largest in position 7. Standard deviation of radial distances is large at positions 4 and 7.

Table B.1 — Example report of the evaluation test of surface shape measurement

Name of body scanner (name of manufacturer)	Bodyline scanner C9036–02[a] (Hamamatsu photonics)
Evaluated by	Digital Human Research Centre, National Institute of Advanced Industrial Science and Technology (AIST)
Date of test	26 May, 2009
Place of test	Digital Human Research Centre, AIST, 2-3-26 Aomi Koto-ku, Tokyo 135-0064, Japan
1. Test object (sphere)	
Material	Steel

[a] This trade name is provided for reasons of public interest or public safety. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO.

Table B.1 *(continued)*

Surface treatment		Blasted and TiN treated		
Calibrated by		National Metrology Institute of Japan, AIST		
Diameter		120,015 93 mm		
Spherical form dispersion value (100)		0,018 96 mm		
2. Results				
Position		**Error of diameter measurement** mm	**Spherical form dispersion value (90)** mm	**Standard deviation of radial distances** mm
1	Same with specification	1,867	6,004	1,854
2	Same with specification	−0,303	2,164	0,682
3	Same with specification	1,447	3,311	1,035
4	Same with specification	3,344	3,391	4,039
5	Height was 1 900 mm	1,484	5,214	1,622
6	Same with specification	1,180	3,937	1,226
7	Same with specification	2,291	10,326	3,156
8	Same with specification	0,167	6,384	2,055
9	Same with specification	2,515	7,338	2,080
3. Figures of measured test sphere				
Position 1		Position 2		Position 3
				
Position 4		Position 5		Position 6
				
Position 7		Position 8		Position 9
				
[a] This trade name is provided for reasons of public interest or public safety. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO.				

B.2 Evaluation of repeatability of landmark positions

B.2.1 General

A whole-body scanner was evaluated according to the protocol described in this document.

B.2.2 Test object

An anthropomorphic dummy as shown in Figure A.2 was used. The material was FRP. The surface colour was grey. The surface diffused the light. It took the posture for circumference measurements as recommended in ISO 20685-1. The body dimensions of the dummy were the mean body dimensions of Japanese women in their 20s. Landmark positions were marked with small dents.

B.2.3 Procedure

Marker stickers specific to the body scanner were pasted on the positions of the 47 landmarks listed in Table 1.

In this body scanner, the foot position is specified on the platform. A line was drawn on the platform to define the heel position. The dummy was measured 10 times at the recommended positions shown in Table 2.

In this body scanner, the positions of marker stickers are automatically detected and the coordinates of landmark positions are calculated. Automatically detected landmark coordinates were not manually corrected. Landmarks were automatically labelled. Landmark names were examined and corrected when necessary.

Obtained landmark positions were examined and 34 landmarks with coordinates from all 10 scans, excluding vertex, were used for further analysis. Vertex was excluded because the position of this landmark was automatically calculated.

Landmark position data from 10 scans were superimposed using the iterative closet point (ICP) method. Each of the 10 scans was used as the base data and each of the remaining nine scans was superimposed on the base data. After the superimposition, the distance between corresponding scanned landmarks was calculated for all pairs of 10 scans (9 × 10 = 90 pairs) for each landmark. Software developed for this purpose was used for the superimposition.

Mean and standard deviation of errors were calculated as those of the 90 distances for each landmark.

B.2.4 Report

Results are shown in Table B.2 as a report.

Table B.2 — Example report of the evaluation test of landmark repeatability

Name of body scanner (name of manufacturer)	Bodyline scanner C9036–02[a] (Hamamatsu photonics)
Evaluated by	Digital Human Research Centre, National Institute of Advanced Industrial Science and Technology (AIST)
Date of test	26 May, 2009
Place of test	Digital Human Research Centre, AIST, 2-3-26 Aomi Koto-ku, Tokyo 135-0064, Japan
1. Test object (Anthropomorphic dummy)	
Material	FRP
Surface treatment	Colour is grey, diffuses the light. Landmark positions are marked with small dents.
Size	Body dimensions of the dummy manually measured using the premarked landmark positions agree with the mean values of Japanese women in their 20s. Body height is 1 580 mm.
Manufacturer	Nanasai Co. Ltd
Number of tested landmarks	47 landmarks listed below
2. Results	
1) Number of scans in which coordinates could be calculated	

NOTE No 1 vertex (top of head) was excluded from analysis because it was automatically calculated rather than calculated from the marker position.

[a] This trade name is provided for reasons of public interest or public safety. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO.

Table B.2 *(continued)*

No	Landmark	Number of scans
1	Vertex (top of head) (automatically calculated position)	10
2	Tragion, right	10
3	Tragion, left	2
4	Orbitale – Infraorbitale, right	10
5	Orbitale – Infraorbitale, left	10
6	Glabella	8
7	Sellion	2
8	Menton	0
9	Opisthocranion	10
10	Cervicale	10
11	Acromion, right	1
12	Acromion, left	7
13	Mesosternale	10
14	Thelion, right	10
15	Thelion, left	10
16	Iliocristale, right	10
17	Iliocristale, left	10
18	Iliospinale anterius – Anterior superior iliac spine, right	10
19	Iliospinale anterius – Anterior superior iliac spine, left	10
20	Stylion (radial stylion), right	10
21	Stylion(radial stylion), left	8
22	Ulnar stylion, right	10
23	Ulnar stylion, left	10
24	Tibiale, right	10
25	Tibiale, left	10
26	Lateral malleolus, right	0
27	Lateral malleolus, left	0
28	Suprapatella, standing, right	10
29	Suprapatella, standing, left	10
30	Neck shoulder point, right	10
31	Neck shoulder point, left	10
32	Front neck point	10
33	Anterior axilla point, right	10
34	Anterior axilla point, left	10
35	Posterior axilla point, right	10
36	Posterior axilla point, left	4
37	Omphalion	10
38	Trochanterion, right	10
39	Trochanterion, left	10
40	Buttock point, right	10

NOTE No 1 vertex (top of head) was excluded from analysis because it was automatically calculated rather than calculated from the marker position.

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Table B.2 *(continued)*

41	Buttock point, left		10
42	Radiale, right		10
43	Radiale, left		10
44	Mid patella, right		10
45	Mid patella, left		10
46	Sphyrion, right		0
47	Sphyrion, left		0
2) Mean and standard deviation of errors (mm) (N = 90)			
No	**Landmark**	**Mean error**	**Standard deviation of errors**
2	Tragion, right	2,5	1,7
4	Orbitale – Infraorbitale, right	2,0	1,0
5	Orbitale – Infraorbitale, left	1,0	0,7
9	Opisthocranion	1,6	1,0
10	Cervicale	1,9	1,1
13	Mesosternale	2,2	1,4
14	Thelion, right	1,8	1,2
15	Thelion, left	1,6	0,9
16	Iliocristale, right	2,1	1,2
17	Iliocristale, left	2,2	1,5
18	Iliospinale anterius – Anterior superior iliac spine, right	2,1	1,4
19	Iliospinale anterius – Anterior superior iliac spine, left	2,8	1,4
20	Stylion (radial stylion), right	2,3	1,1
22	Ulnar stylion, right	2,2	1,0
23	Ulnar stylion, left	1,4	0,8
24	Tibiale, right	2,9	1,8
25	Tibiale, left	2,5	1,7
28	Suprapatella, standing, right	2,3	1,7
29	Suprapatella, standing, left	2,3	1,6
30	Neck shoulder point, right	1,2	0,8
31	Neck shoulder point, left	1,3	0,6
32	Front neck point	1,9	1,2
33	Anterior axilla point, right	2,4	1,3
34	Anterior axilla point, left	2,2	1,1
35	Posterior axilla point, right	2,0	1,0
37	Omphalion	2,9	1,2
38	Trochanterion, right	2,5	1,1
39	Trochanterion, left	3,1	1,7
40	Buttock point, right	3,0	1,3
41	Buttock point, left	3,2	1,8
42	Radiale, right	2,2	1,2

NOTE No 1 vertex (top of head) was excluded from analysis because it was automatically calculated rather than calculated from the marker position.

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Table B.2 *(continued)*

43	Radiale, left	3,0	1,7
44	Mid patella, right	2,6	1,7
45	Mid patella, left	1,8	1,6

NOTE No 1 vertex (top of head) was excluded from analysis because it was automatically calculated rather than calculated from the marker position.

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Annex C
(informative)

Example of report of evaluation of hidden area

Table C.1 shows an example of a report. Figure C.1 shows examples of missing areas.

Table C.1 — Example of report

<table>
<tr><td>Name of body scanner (name of manufacturer)</td><td colspan="3">Bodyline scanner C9036–02[a] (Hamamatsu photonics)</td></tr>
<tr><td>Evaluated by</td><td colspan="3">Digital Human Research Centre, National Institute of Advanced Industrial Science and Technology (AIST)</td></tr>
<tr><td>Date of test</td><td colspan="3">26 May, 2009</td></tr>
<tr><td>Place of test</td><td colspan="3">Digital Human Research Centre, AIST, 2-3-26 Aomi Koto-ku, Tokyo 135-0064, Japan</td></tr>
<tr><td>Automatic fill hole</td><td colspan="3">The system has automatically filling hole function, but it was not used</td></tr>
<tr><td colspan="4">1. Participants
15 adult Japanese females 157,5 (147,0 to 164,8) cm, 52,2 (39,6 to 68,2) kg, 21,1 (17,6 to 31,6) kg/m²
15 adult Japanese males 169,8 (160,9 to 177,3) cm, 62,3 (49,4 to 83,6) kg, 21,6 (19,1 to 29,6) kg/m²</td></tr>
<tr><td colspan="4">2. Procedure
Data captured by each camera head was exported in the text format and Geomagic Studio[a] was used to visualize the surface data.</td></tr>
<tr><td colspan="4">3. Results (yes indicates the existence of missing area)</td></tr>
<tr><td>Code number</td><td>Area</td><td>No of participants with missing area: total number (female, male)</td><td>Comments</td></tr>
<tr><td>10</td><td>Top of the head</td><td>30 (15, 15)</td><td>Small missing area</td></tr>
<tr><td>11</td><td>Under the nose</td><td>4 (3, 1)</td><td></td></tr>
<tr><td>12</td><td>Back of the ear</td><td>9 (3, 6)</td><td></td></tr>
<tr><td>13</td><td>Pupil</td><td>1 (1, 0)</td><td></td></tr>
<tr><td>14</td><td>Under the chin</td><td>30 (15, 15)</td><td>Size varies according to the shape</td></tr>
<tr><td>20</td><td>Over the shoulder</td><td>20 (15, 5)</td><td>Small missing area</td></tr>
<tr><td>21</td><td>Armpit and trunk</td><td>30 (15, 15)</td><td>Small missing area</td></tr>
<tr><td>22</td><td>Under the bust</td><td>10 (9, 1)</td><td>Size varies according to the shape</td></tr>
<tr><td>23</td><td>Under the buttocks</td><td>10 (5, 5)</td><td>Small missing area</td></tr>
<tr><td>24</td><td>Under the crotch and the medial side of the thighs</td><td>30 (15, 15)</td><td>Large missing area at the medial side of the thighs</td></tr>
<tr><td>25</td><td>Side of the body, arms and legs</td><td>0 (0, 0)</td><td></td></tr>
<tr><td>30</td><td>Trunk side of the arm</td><td>30 (15, 15)</td><td>Large missing area in the upper arms; size varies according to the shape</td></tr>
<tr><td>40</td><td>The plantar part of the foot</td><td>30 (15, 15)</td><td>Plantar part is completely missing</td></tr>
</table>

Table C.1 *(continued)*

Other	Above the clavicle	10 (6, 4)	Missing area exists when there is a hollow
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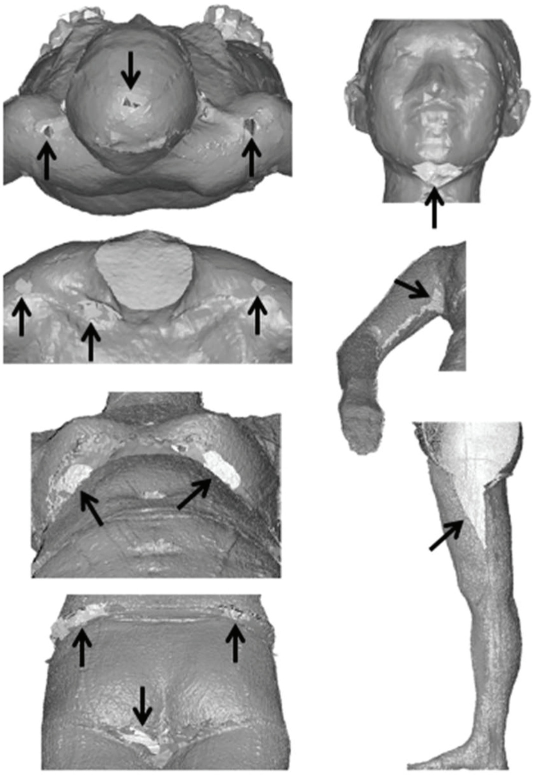

NOTE Arrows indicate missing areas.

Figure C.1 — Example of missing areas

Annex D
(informative)

Superimposition of landmark coordinate data from 10 scans and calculation of quality parameters

D.1 General

Superimposition means to register (move) the coordinate system of one set of scan data to that of another set of scan data by minimizing the sum of distances between corresponding landmarks of the two sets of scan data. The iterative closest point (ICP) method is used for this procedure.[3] Since the test object is the same, size normalization is not required.

D.2 Procedure

Step 1: Coordinates of landmarks are obtained by the available method for 10 scans of the same dummy. Select scan 1 as the base data.

Step 2: Superimpose each of the remaining nine scans on the base data by minimizing the sum of distances between corresponding landmarks of the base data and the other scan.

Step 3: After superimposition, for each landmark, calculate the distance between corresponding landmarks of the two scans.

Step 4: Step 2 and step 3 are repeated using each of scans 2 to 10 as the base data. This step is done because the results of superimposing data A to data B could be different from the results of superimposing data B on data A.

Step 5: For each landmark, mean error and standard deviation of errors are calculated using the distances calculated in step 3. The number of distances is 90 (10 * 9), where 10 is the number of the base data and nine is the number of superimposed scan data.

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[1] ISO/TR 7250-4[2)] , *Basic human body measurements for technological design – Part 4: Expected performance of skilled anthropometrists*

[2] Kouchi, M., Mochimaru, M., Bradtmiller, B., Daanen, H., Li, P., Nacher, B., Nam, Y. A protocol for evaluating the accuracy of 3D body scanners. *Work*. 2012, 41(suppl.) 4010–4017

[3] Besl, P. J., McKay, N.D. A method for registration of 3-d shapes. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 1992, 14(2), 239–256

2) Under preparation. Stage at the time of publication: ISO/DTR 7250-4:2023.

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