Development of body shape data based digital human models for ergonomics simulations

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Abstract

This paper presents the development of body shape data based digital human models, i.e. manikins, for ergonomics simulations. In Digital human modelling (DHM) tools it is important that the generated manikin models are accurate and representative for different body sizes and shapes as well as being able to scale and move during motion simulations. The developed DHM models described in this paper are based on body scan data from the CAESAR anthropometric survey. The described development process consists of six steps and includes alignment of body scans, fitting of template mesh through homologous body modelling, statistical prediction of body shape, joint centre prediction, adjustment of posture to T-pose and finally generation of relation between predicted mesh and manikin mesh. The implemented method can be used to create any type of manikin size that directly can be used in a simulation. To evaluate the results a comparison was done of original body scans and statistically predicted meshes generated in an intermediary step as well as the resulting DHM manikins. The accuracy of the statistically predicted meshes are relatively good even though differences can be seen, mostly related to postural differences and differences around smaller areas with distinct shapes. The biggest differences between the final manikin models and the original scans can be found in the shoulder and abdominal area, in addition to the significantly different initial posture that the manikin models have. To further improve and evaluate the generated manikin models additional body scan data sets that includes more diverse postures would be useful. DHM tool functionality could also be improved to enable evaluation of the accuracy of the generated manikin models, possibly resulting in DHM tools more compliant with standard documents. At the same time standard documents might need to be updated in some aspects to include more three-dimensional accuracy analysis.

Keywords: Anthropometry, 3D body scanning, body shape, statistical body model, joint centre.

Introduction

Digital human modelling (DHM) tools are useful when evaluating human-machine interaction and enables consideration of anthropometric diversity by creating human models, so called manikins, of different sizes and proportions. This functionality is a central feature when using DHM tools for product and production development to ensure that the design fits the intended proportion of the targeted population, from a physical perspective (Duffy, 2009; Scataglini & Paul, 2019). Therefore, it is important that these generated manikin models are accurate and representative for different body sizes and shapes, for both women and men, as well different age groups. To be compliant with standard documents functionality should exist in DHM tools that enables manikin measurement and data documentation (ISO, 2005; ISO, 2007). Since the first big body scanning based anthropometric survey CAESAR (Robinette et al., 2002) numerous additional surveys have been conducted around the world. Three-dimensional body scan data makes it possible to accurately recreate body shapes using statistical models with input data of more one-dimensional anthropometric data, e.g. stature, body weight and sitting height (Allen et al., 2003). Additional mathematical models exist that describes how joint centres are related to anthropometric landmarks in a three-dimensional space (Reed et al., 1999; Murphy et al., 2011; Hara et al., 2016). Using statistical body shape models in combination with joint centre equations makes it possible to generate manikin models with realistic and accurate body shapes as well as a biomechanical skeleton (Reed et al., 2014). This paper presents the development and implementation of body shape data based digital human models for ergonomics simulations in a demonstrator version of the Swedish DHM tool IPS IMMA (Intelligently Moving Manikins) (Högberg et al., 2016). The current version of the IPS IMMA manikin´s mesh model only scales in the length directions of each body part and not enough regarding circumference and depth measurements and therefore needs to be updated and improved.

Methods

The body shape data based digital human models described in this paper are based on body scan data from the CAESAR anthropometric survey. Specifically, the North American data set is used and the motivation behind this choice is that this data set has a large sample size and diversity considering the range of measurement values for the anthropometric one-dimensional data. The described development process includes 6 steps:

1. Rotate and translate landmark data as well as body scan point cloud
2. Homologous body modelling to fit body scan point cloud with template mesh
3. Statistical prediction of landmarks and mesh
4. Joint centre prediction based on landmarks and mesh
5. Adjust posture to T-pose

6. Align statistical mesh with clothed manikin mesh and calculate relation between meshes

In first step using data of landmark pairs, found on both sides of the mid sagittal plane, a suitable rotation angle around the vertical axes could be calculated. Based on landmarks known to be found on the mid sagittal plane, together with the known height of the measuring platform for each subject, a translation distance in three-dimensional space could be calculated. Through a MATLAB (The Math Works Inc., 2021) script these rotation angles and translation distances were used to align all body scan point clouds (1118 women and 1254 men) in a similar position and orientation (Figure 1).

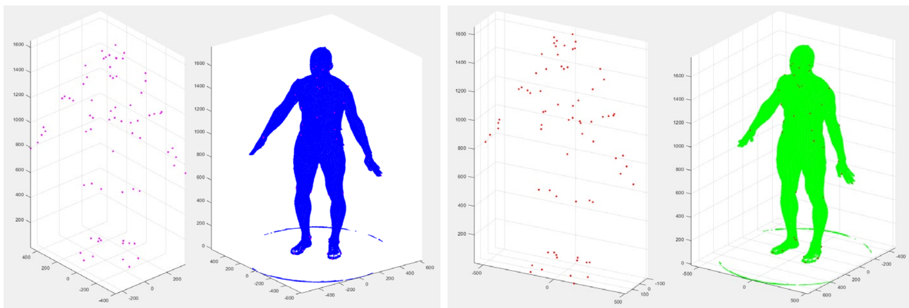


Figure 1. Landmarks and point cloud rotated and translated

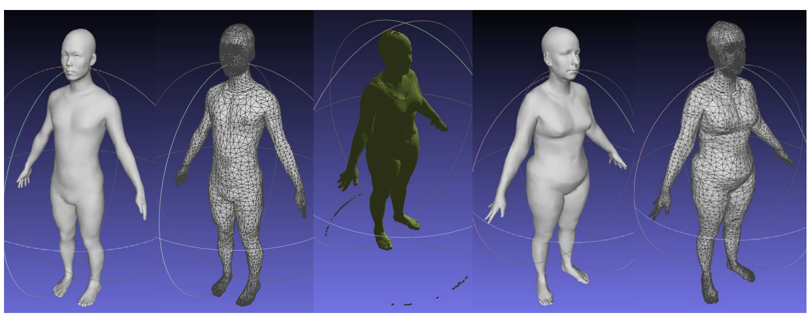


Figure 2. Template mesh (left) fitted to (right) body scan point cloud (middle)

In the second step, after the alignment had been done, a template mesh was fitted to all body scan point clouds using the software mHBM (Markerless Homologous Body Modelling) (Yamazaki et al., 2013) (Figure 2). Fitting of the template mesh was successful for most subjects but the sample size used in the statistical analysis was reduced to 849 women and 838 men. In the third step, the fitted template mesh and landmark data were used to generate statistical prediction of both landmark points and mesh vertices coordinates. The statistical prediction was done in a two-step procedure where 73 landmarks were first predicted based on 44 anthropometric measurements, including age. Principal component regression was used where the number of principal components used in the regression was 32 for the male data and 34 for the female data. The coordinates of the landmarks were adjusted to make pairs symmetrical and mid points aligned to the mid sagittal plane. Then all mesh vertices were predicted based on the predicted landmark coordinates as well as age, stature and weight. The number of principal components used in the second regression was 116 for the male data and 120 for the female data. In the fourth step, based on the statistically predicted landmarks points and mesh vertices internal joint centre locations could be estimated using methods found in literature (Reed et al., 1999; Murphy et al., 2011; Hara et al., 2016). In the fifth step, the posture of the statistically predicted mesh, including landmarks and joint centre locations, was adjusted into a T-pose to be able to align it to the clothed IPS-IMMA manikin mesh (Figure 3). The T-pose adjustment was done by rotating landmark and mesh vertices around the glenohumeral, acromioclavicular, and sternoclavicular joints using estimation of how the movements in these joints contributes to a final T-pose (Inman et al., 1944). In the sixth step, the two meshes were aligned in Blender (Blender Online Community, 2018) (Figure 3) where a relationship was established where the ten closest mesh vertices of the statistical mesh were used to predict the position of each mesh vertex on the clothed IPS-IMMA mesh. Step 3-5 were initially realized through MATLAB (The Math Works Inc., 2021) scripts but then translated and implemented into the IPS-IMMA software using C++ (ISO/IEC (2014).

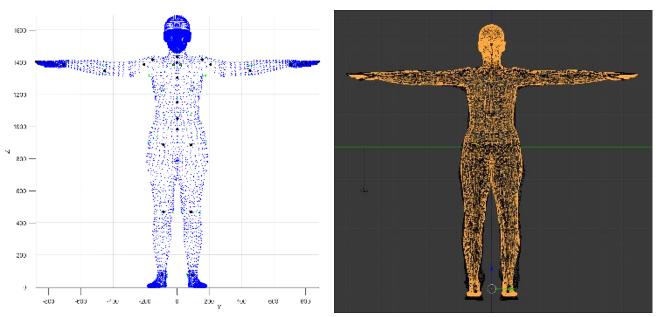


Figure 3. Template mesh adjusted to T-pose and aligned with IPS-IMMA manikin mesh in Blender.

Results

By using the functionality of predicting one-dimensional anthropometric data in IPS-IMMA, the implemented method can be used to create any type of manikin size that directly can be used in a simulation, Figure 4.

Figure 4. Body scan based IPS-IMMA manikins used in a simulation.

Table 1: Measurement from six subjects used for evaluation of generated models

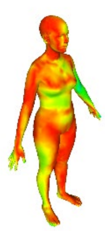
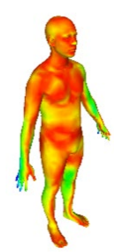
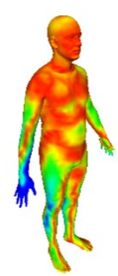
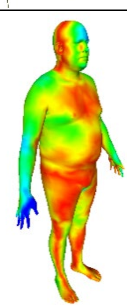
Description	**F1 (S)**	**F2 (M)**	**F3 (L)**	**M1 (S)**	**M2 (M)**	**M3 (L)**
Sex	Female	Female	Female	Male	Male	Male
Age (years)	30	30	34	34	32	47
Body mass (kg)	50	68	89	68	85	123
Stature (mm)	1530	1634	1774	1641	1771	1901
Crotch height (mm)	701	766	824	709	806	828
Sitting height (mm)	810	858	915	885	926	953
Biacromial breadth (mm)	352	375	388	433	413	446
Bideltoid breadth (mm)	384	432	472	482	480	560
Hip breadth, sitting (mm)	375	397	425	350	380	444
Hand length (mm)	174	186	203	187	207	221
Foot length (mm)	232	244	260	240	265	282
Foot breadth (mm)	87	99	106	97	106	113
Head length (mm)	186	191	191	195	205	215
Head breadth (mm)	136	149	147	156	160	156
Face length (mm)	105	113	117	116	124	141
Buttock-knee length (mm)	551	567	627	570	613	691

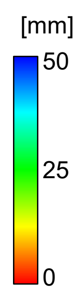
To evaluate the validity of the generated digital human models based on standard documents it would be necessary to posture the manikins in predefined postures and provide coordinates of the landmarks (ISO, 2007). This is not possible in the current version of IPS-IMMA and therefore a comparison was done of the original body scan and the resulting IPS-IMMA manikin of six subjects (3 women and 3 men) with different body sizes, Table 1. In addition, the statistically predicted mesh generated in an intermediary step is also used in the comparison, Table 2. Since the IPS-IMMA manikin is dressed the comparison between the final manikins and the original body scans is done visually. The statistically predicted intermediary meshes are evaluated with heatmap colours based on the distance differences between the predicted mesh and the original body scans of the selected test subjects.

Discussion and Conclusions

The results show that the method presented in this paper is able to produce manikin models with different body shapes that can be used in ergonomics simulations. The accuracy of the statistically predicted meshes are relatively good even though differences can be seen. These differences are mostly related to postural differences as the statistically predicted meshes have an average posture based on all included body scans and are centred and symmetrical on both sides of the mid-sagittal plane. Differences can also be seen regarding smaller areas with distinct shapes, i.e. muscles in the torso. Since the meshes are predicted with statistical regression, which predicts the most likely (average) body shape based on the input data, it is difficult to recreate finer details of a person's body shape. The final manikin models show a relatively good similarity with the original scans but there are some areas that needs to be improved. Biggest differences between the final manikin models and the original scans can be found in the shoulder and abdominal area. The manikin models also have an initial neutral posture that significantly differs from the postures in the original scans.

Table 2. Comparison of the original body scans, statistically predicted meshes and IPS-IMMA manikins

Subject	F1 (S)	F2 (M)	F3 (L)	M1 (S)	M2 (M)	M3 (L)
Original body scans						
Statistically predicted meshes*						



* The colours on the statistically predicted meshes indicates distance differences with the original body scans according to the scale on the right.

A conclusion is that improvement potential exists, both related to the generation of the manikin models as well as functionality for evaluating the accuracy of the models. The CAESAR data set that the presented method is based on is a relatively old body scan survey and only provides data in one standing posture and two seated postures. Additional data sets that includes more diverse postures would be useful for improving and evaluating the manikin models, e.g. body scan data sets with seated posture to show and evaluate how soft tissue deforms when seated (Park, 2021). In addition, improved and usable tool functionality needs to be developed for evaluating the accuracy of generated manikin models, compared to measurements of real people that manikins are modelled after. This would make DHM tools more compliant with standard documents, i.e. *ISO 15536-2 – Ergonomics – Computer manikins and body templates – Part 2: Verification of functions and validation of dimensions for computer manikin systems* (ISO, 2007). To realise such functionality, it would be necessary to have an undressed manikin as the base mesh and include the predicted posture of the manikin when generating it in the DHM tool. As stated in Reed et al. (2014) the question what should be considered as an acceptably accuracy is still not answered as standard documents only provide guidance of how the accuracy should calculated and documented based on one-dimensional anthropometric measurements (ISO, 2007). It could be argued that such accuracy analysis also should include distance analysis of three-dimensional data from body scan point clouds and fitted template meshes compared to the body shape of manikin meshes, which indicates that the standard documents might need to be updated and improved in some aspects. The body shape data based digital human models will be continually developed and are intended to be fully implemented in the DHM tool IPS IMMA to be able to better represent the diversity of humans for the design of products and work environments.

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