# A Markerless Method for Personalizing a Digital Human Model from a 3D Body Surface Scan

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## Abstract

Digital Human Models (DHM) are used for ergonomic design of products. For instance, vehicle ingress/egress motions are simulated for assessing vehicle accessibility. In order to validate simulations, experiments are often needed implying motion capture and motion reconstruction using a DHM. The first step for motion reconstruction is to create a personalized DHM respecting the anthropometric dimensions of the volunteer performing the task. However creating a personalized DHM from external body shape is not straight forward, because the internal skeleton has to be identified from external body shape. Here we propose a four-step method for generating a personalized DHM which matches a 3D scan. The first step is to clean the scan data and to prepare a DHM and a third body surface template. Then, thanks to the use of the third common body template, the correspondence between the DHM and scan surface points is established, making it possible to calculate the transformation parameters by kriging. From estimated position of joint centers, the internal skeleton is scaled and positioned from a known reference posture to the scan position. The third step is then to attach the surface points to their corresponding skeletal segments. The last step is to check and correct the attached skin points around some joints so as to respect the skin to segment structure specific to a DHM. Compared to the method used in the past by manually adjusting a DHM on calibrated photos of several points of views; the proposed method is operator independent and much less time consuming.

**Keywords:** Digital Human Models, Template, non-rigid registration, bodyscan

## 1. Introduction

Digital Human Models (DHM) are now used to simulate the human interacting with an environment for ergonomics assessment of a product such as a vehicle [1]. For example, RAMSIS [2] is a DHM software package largely used for vehicle interior design. We can also mention two other DHMs, SAFEWORK (now Human Builder under CATIA) [3] and JACK [4]. These digital human modeling systems are able to represent future users of different anthropometric characteristics thanks to integrated anthropometric database of different populations. The DHM skin surface is commonly composed of about 2500 triangular faces. The skin points are defined locally relatively to the corresponding skeleton's segment, distributed over a certain number of sections along the segment. They also have a kinematic linkage representing the human skeleton with more than 100 degrees of freedom allowing simulating different postures and movements. In general, joints are simplified with one to three rotation axes without translation. Number of joints and rotation axes (or degrees of freedom) is model specific. For instance, RAMSIS has a simplified spine with only seven joints approximatively approaching the locations of S2/S3 (GLK), L4/L5 (GLL), T12/L1 (GBL), T8/T9 (GBB), T4/T5 (GHB), C4/C5 (GHH), C1/head (GKH), while Human Builder includes a full representation of the thoracic and lumbar spine.

In order to simulate complex task oriented motions, different data-based approaches have been proposed in recent years ([5], [6]). For this, real motions performed by volunteers need to be captured, reconstructed and analyzed in order to constitute a task specific motion database. The first step for motion reconstruction is to define a personalized DHM matching to the anthropometric dimensions of the volunteer (See [7] for a review of existing motion reconstruction methods). Most of existing DHMs have a module for generating manikins from a few external anthropometric dimensions.

For Human Builder, up to 70 anthropometric measurements such as stature, sitting height, weight can be used for the DHM personalization. In practice, not all required anthropometric measures are available. The missing parameters are automatically estimated from a chosen anthropometric database.

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A similar procedure can be found in RAMSIS, which uses 22 anthropometric dimensions. Though generated manikins could have a good representation of external anthropometric dimensions such as stature, sitting height, etc., more detailed external body shape is not guaranteed compared to the real external shape of the volunteer. An alternative way is to adjust a DHM so as to match it by superimposition with the photos of at least two different views ([8]). However, this procedure is tedious, time consuming and operator dependent.

3D body scanning technologies are becoming accessible, and more and more 3D scan data are available. But creating a personalized DHM from a scanned external body shape is not straight forward, because the internal skeleton has to be identified from external body shape. More critically, the local coordinate system associated to each body segment of a DHM need to be defined so as to attach skin points to corresponding body segments. Moreover, attached skin points have to follow the skin-to-segment structure especially around the joint areas. Joint centers can be estimated using external anatomical landmarks (ALs) as proposed by Reed et al [9]. However it is difficult in locating ALs and requires specific training for palpation. Moreover, joint centers alone are not enough to completely define the local coordinate system associated to each body segment.

Therefore, the main objective of the present paper is to present an operator independent method to personalize a DHM from 3D body scans data without using ALs. To illustrate the proposed approach, RAMSIS is used in the present work as DHM.

## 2. Proposed approach

### 2.1 Overview

Fig.1 presents an overview of the proposed approach for generating a personalized DHM model from a 3D bodyscan. It consists in four main steps:

1) Preparation
2) Transforming DHM template to bodyscan
3) Attaching surface points to the DHM skeleton
4) Correcting the attached surface points to the skeleton respecting the DHM structure.

The first step is to create a DHM reference template (a) and to clean the 3D scan data. The DHM template is composed of a body surface and an articulated internal skeleton. In the present work, a template corresponding to a $50^{th}$ percentile male was used. Raw 3D body scan data generally needs to be cleaned to get a usable surface mesh (b). This step is detailed in Section 2.2.

The second main step is to determine the transformation which deforms the DHM template so as to match the bodyscan mesh without using landmarks. This step is detailed in Section 2.3. The outputs are the DHM surface points fitted to the bodyscan mesh (c) as well as the DHM joint centers (d) in a global coordinate system.

The third step (Section 2.4) is to attach the surface points to the underlying skeletal segments. For this, body segment local coordinate systems (f) need to be calculated from the estimated joint centers. This step is detailed in Section 2.3.

The last step (Section 2.5) is to correct the attached surface points for each segment according to the segment-surface points structure specific to each DMH.

At the end, a personalized DHM (g) is generated respecting the skin to skeleton structure specified by each DHM.

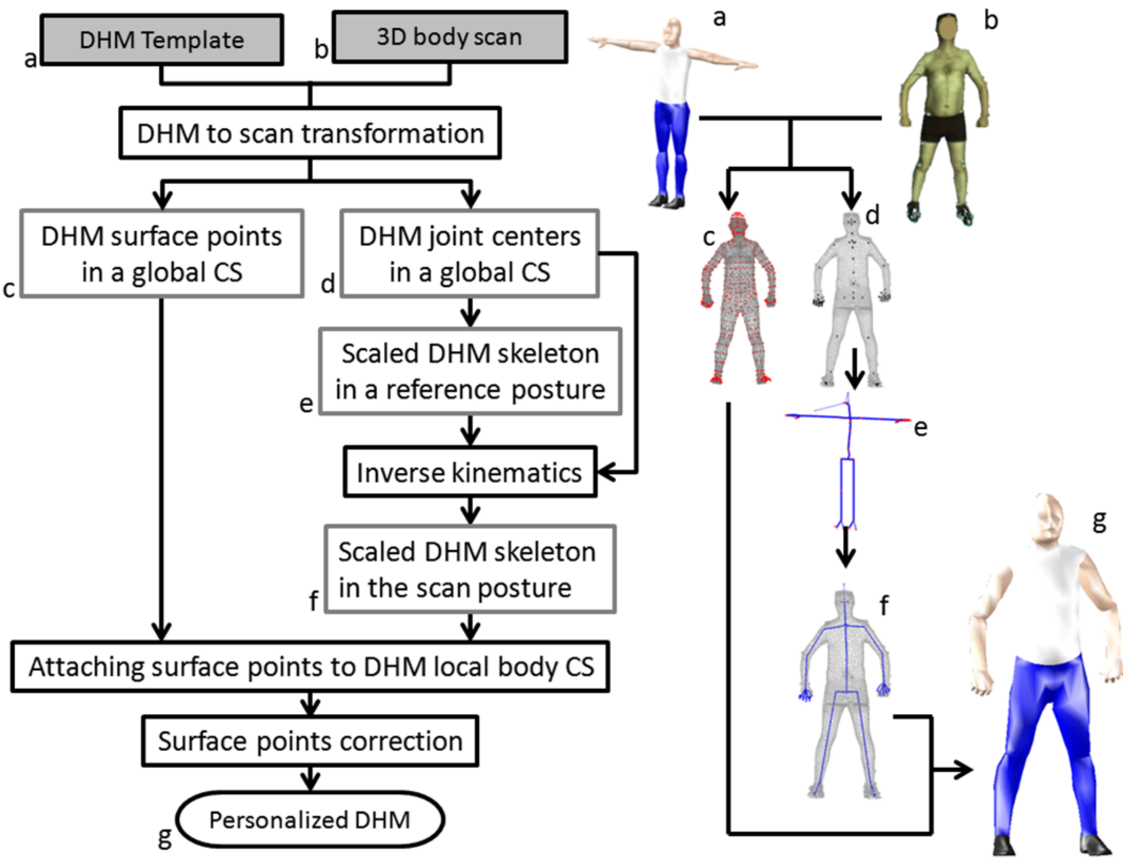



*Fig. 1. Overview of the proposed approach*

## 2.2 Preparation

*2.2.1 Preprocessing of scan data*

In this study, the scan data in a standing position were obtained (Fig 2) using the body scanning system SYMCAD$^{TM}$ II commercialized by Telmat [10], which provides a textured mesh with a density of about a point every 3 mm. The bodyscan mesh data presents holes at all extremities (hands, feet, and head) as well as under the arms. The meshes can be also locally deformed due to Vicon markers attached on body surface used for motion capture.

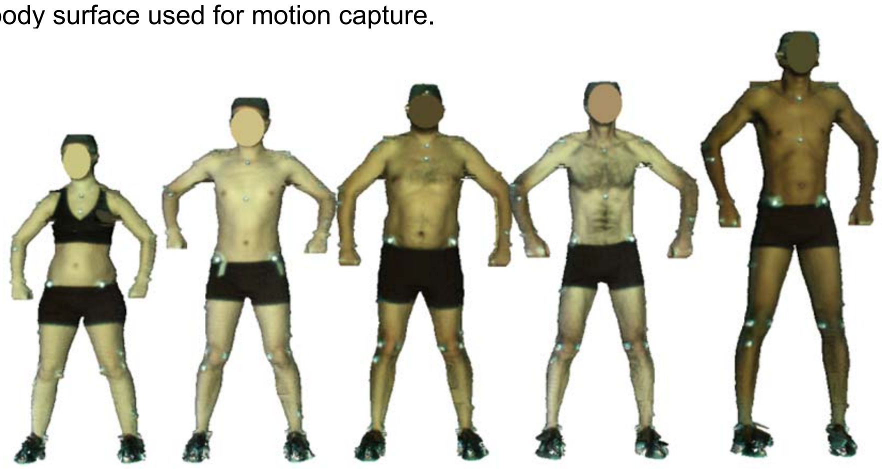
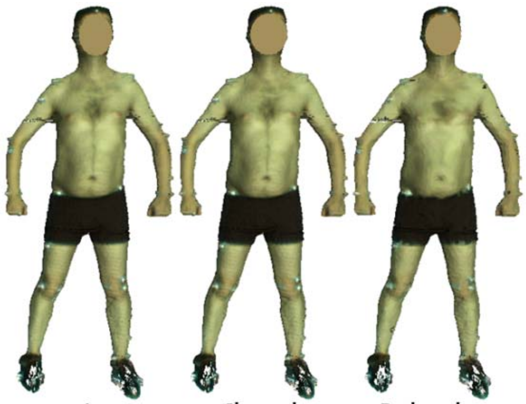


*Fig. 2. Screen capture of some subjects bodyscan mesh with the Symcad II standard posture - same scale*

The scan data were first cleaned using MeshLab [11] by removing duplicate vertices and faces, non-manifoldness… The number of points was also reduced to a density similar to the third body template used for the DHM to scan transformation step.



| | Input | Cleaned | Reduced |
|---|---|---|---|
| Vertices | 137522 | 135456 | 9718 |
| Faces | 270076 | 265509 | 17891 |

*Fig. 3. Data processing results for the bodyscan post treatment*

### *2.2.2. DHM and a third body surface reference templates*

DHM template

The surface of the RAMSIS DHM model used is composed of 1292 vertices and 2490 faces. The kinematical skeleton is composed of 56 joint centers. Each joint center has 1 to 3 degrees of freedom (DOFs) in rotation for a total of 104 DOFs. The pelvis as the root segment has also 3 DOFs in translation.

The surface points are distributed in a number of sections along the underlying segment. Each section has 6 to 16 points in a ring shape. When the DHM is set to the zero reference posture (i.e. all joint angles set to zero), most of the sections are parallel.

In order to control the shape deformation around a joint area, a few mobile sections are introduced. When the proximal and distal segments are aligned, these mobile sections are superimposed. For instance, a mobile section is defined around the elbow. Figure 4 shows how the mobile sections move when flexing the elbow.

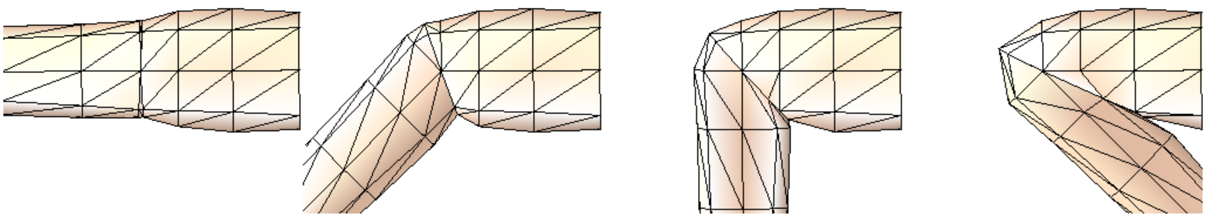


*Fig. 4. Elbow shape in different flexion angles by a step of 45° (view from top)*

In the present work, a RAMSIS template was created based on an existing model corresponding to a 50$^{th}$ percentile male. The template was positioned by manually adjusting joint angles approaching the scan standing position.

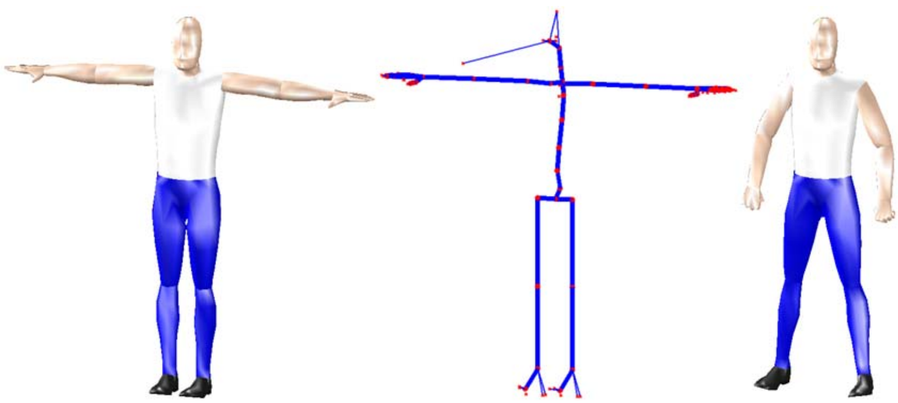


*Fig. 5. RAMSIS template, from the left : zero reference posture, kinematical skeleton, scan posture*

Third human body template

In order to calculate the DHM to scan transformation (see 2.3), a third body surface reference template is needed. In the present work, the template mesh corresponds to an average male from MakeHuman [12]. The template mesh was initially posed with Blender [13] in a posture similar to the scan posture. A particular attention was paid to the forearm axial rotation (pronation/supination) for a good fit to scan. The template mesh was simplified manually using Blender by removing internal parts (tongue, teeth, eyes …) as well as small faces. Moreover, due to the hole at the top of the head in the scan data, the top of the head of the MH template was also removed to avoid large head deformation. At the end, the third template used is composed of 17992 faces and 9020 vertex (Fig 6).

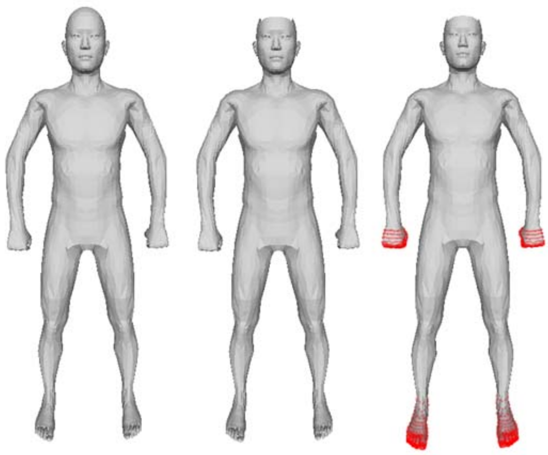


*Fig. 6. Template definition: (a) MakeHuman posed and simplified, (b) with the top of the head removed, (c) in red the rigidified vertices*

### 2.3 Transformation from DHM template to scan data

In order to avoid the use of body landmarks to fit the DHM template to the scan, we propose to use a third body surface template created from MakeHuman (MH). The MH template is fit to the scan and also to the DHM reference surface using mHBM, a robust markerless non-rigid transformation tool developed by Japan National Institute of Advanced Industrial Science and Technology (AIST) [14]. As the two deformed surfaces from a same MH template have the same data structure, a DHM to scan transformation can then be calculated with a kriging operation [15] using all or part of surface points. In the present study, half of the points were used.

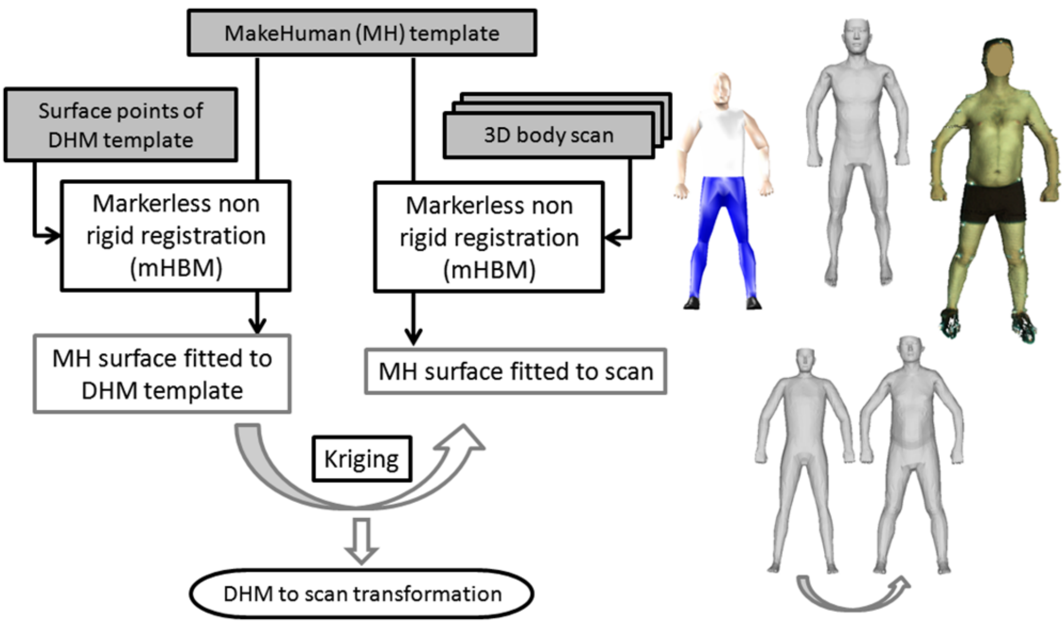



*Fig. 7. Principle of the determination of the DHM to scan transformation*

### 2.4 Attaching the surface points to skeleton

The third step is to attach the surface points to the underlying skeletal segment. For this, the DHM internal skeleton is dimensioned at first and then positioned in a reference posture with the local coordinate system of all skeleton segments being defined. The RAMSIS reference posture with all joint angles equal to zero was used in the present work, corresponding to a standing posture with the two extended arms pointing laterally (e) (figure 5). Then the scaled skeleton is placed in the same position as the scan posture using an inverse kinematic algorithm with the joint centers as targets, which are obtained by applying the DHM to bodyscan transformation. Once the joint angles corresponding to the scan posture are obtained, the local coordinate system of each skeleton segment can be calculated. The surface points are then projected into the corresponding body segment local coordinate systems (f).

### 2.5 Surface points correction around joint centers for respecting DHM surface to skeleton structure

Once surface points are attached to underlying segments, we need to check if the attached points in the reference posture respect the RAMSIS model structure (see 2.2.2). In particular, the points in the mobile sections and next sections around a joint have to be superimposed. In the present work, the points of one mobile section were chosen to impose to other mobile sections. After the correction step, a personalized RAMSIS DHM is created.

## 3. Implementation and examples

The proposed approach has been implemented using Matlab and tested under the environment of RPx, a Matlab based digital human modelling software package developed jointly by IFSTTAR and Renault [5] for human motion reconstruction, analysis and simulation.

Figure 8 shows an example of a personalized RAMSIS DHM emulated in RPx. Figure 9 shows the personalized DHM in a car ingress motion.

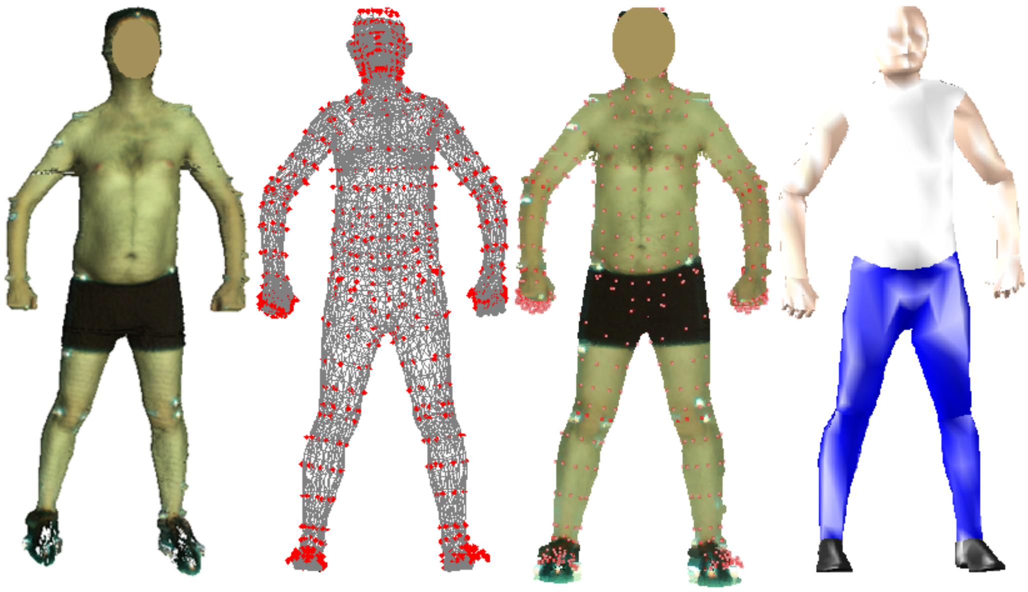


*Fig. 8. From left to right are bodyscan, fitted MH template (grey) superimposed with fitted DHM template (red points), bodyscan superimposed with the personalized DHM skin points (red points), and the personalised DHM.*

*Fig. 9. Personalized DHM performing an ingress motion*

## 4. Discussion and future work

In this paper, a method for generating a personalized digital human model (DHM) from a 3D body scan is proposed. The use of a third body template makes it possible to create the correspondence between DHM and scan surface points and then to calculate the transformation from DHM to scan reference surface points without using body landmarks. By applying the DHM to scan transformation, DHM joint centers are estimated in the scan position. In a recent study [16], the location of the joint centers of RAMSIS and Human Builder DHMs generated using a few anthropometric dimensions was compared with those obtained from two perpendicular x-ray images. Results showed that both RAMSIS and HB could correctly reproduce external anthropometric dimensions, while the estimation of internal joint centers location presented an average error of 27.6mm for HB and 38.3mm for RAMSIS. As an accurate location of joint centers is required for biomechanical and ergonomics analysis of human activities; the joint centers estimated only by fitting the DHM to external body surface may not be anatomically correct. If the DHM template is too far from the anthropometric characteristics of a target person, a big error in joint centers location may be expected. Work at IFSTTAR in collaboration with LBM of ParisTech Art et Métier is in progress to establish the relationship between the characteristics from external body shape and those of the internal skeleton [17]. One way is to predict joint centers from external body shape using a statistical shape modeling approach like that used by Yamazaki et al [14] or Reed et al [18] to predict anatomical landmarks if data containing both external body shape and joint centers are available.

Compared to the method by manually adjusting a DHM to the calibrated pictures of a subject, the present method is operator independent and much less time consuming. Using the proposed method, it takes less than 1 minute to generate a personalized DHM instead of 20 minutes by manual adjusting method.

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