3D Modeling and Size Adaptation of Individual Human Body Avatars from Parametric Measurement Data for 3D Construction and Analysis Tasks

Viktoriya KLEBAN[1], Lothar PAUL[2]
Gesellschaft zur Förderung angewandter Informatik e.V. Berlin (GfaI), Berlin, Germany

Abstract

Realistic human body models, providing individual or table measures and form features, are required for innovative 3D pattern construction of made-to-measure garment and for ergonomic customized equipment design. Typically, not complete information about the form of individual bodies is available from measures or tables, but only crucial parameters like lengths, perimeters or single curvature. That means, sophisticated approaches including anatomical and aesthetic a-priori knowledge and experience are necessary to build or adapt a complete 3D body model from such data. Further, virtual manipulation of body models like positioning of limbs, posture adaptation and motions, particularly without any underlying model of muscles, sinews or fat tissue needs complex mathematics for the achievement of realistic results. The contribution presents analysis and results in an approach based on CSRBFs for 3D modeling and adaptation of human body models, aiming at usage of size tables, BodyFit 3D measures and motion capture records.

Keywords: 3D-Modelling, 3D-Avatar, body parameters, deformation, animation, CSRBFs, construction, ergonomics, orthopedics

1. Introduction

1.1. Motivation

Beside rather artificial and "expressionistic" human avatars, realistic or even customized three-dimensional models of the human body are increasingly requested from very different applications. Primarily, such requests came from cinema, VR arts or gaming industry. Currently virtual human avatars are widely used in education, advertisement, entertainment, and increasingly in medicine, ergonomics or orthopedics. Application demands to the provided models are quite different and so are available data sources and resulting complexity of the models. In some cases, complete inner structures, tissue, bones and sinews and muscles have to be modeled and even provided with applied force models (dynamic models, weightbearing simulation). In such complex tasks, geometric surface deformation usually plays a subdominant role and often – by considerations of calculation complexity – just single body parts, limbs or joints are included into the model (well known examples come from [1]). In cinema, gaming or VR arts, the focus lies at the perfect graphic appearance and performance of the avatars with rather idealized than customized to a concrete individual feature.

Motivation for our work comes from a new particular application field that currently opens for textile engineers and designers. It already became possible to preview virtually designed fashion and garment pieces in realistic colors, fitted on a virtual model, performing at a virtual catwalk etc. Nowadays, modern 3D-technologies open new approaches and methods in pattern construction itself. While singular solutions for 3D-design of tight-fitting garment (swim-suits, corsetry) are already used for a couple of years, currently, designers try to apply these approaches to usual outerwear, taking into account local distances between body surface and fabric[2]. Obviously, realistic and anatomically proper 3D body models (both in body form and posture) are inevitable to solve this kind of task. Ideally, the 3D body model should be quickly and easily adjustable to size, body type, form, posture and even dynamic (motion) characteristics by an editable set of input parameters. On the other hand, product customization plays an increasing role in many areas including but not limited to apparel industry. Merging our experience from cooperation with industrial partners and available publications in the field of body measurement and parametrization [7] [8], we discover a number of challenging potential applications for parametrized and customized avatars potent of adapting to required sizes, of deforming, posturing and virtually moving.

[1]kleban@gfai.de ; [2]paul@gfai.de ; www.gfai.de/forschungsbereiche/3d/3ddv/

1.2. Task description and choice of approach

Compared to the slightly euphoric vision depicted above, the actual objective of our work and the results presented here may seem rather modest. Nevertheless, we see them as important steps towards the aimed targets.

The aim of the work presented in the following was to find and to implement an approach for deformation modeling of human body models, for the moment limited to deformations typically for changes in posture and for walking. As input, a 3D surface mesh model of different body types (female, male, different standard sizes) is given as “the skin”. Furthermore, inside the given hull, a skeleton model of a certain joint complexity is placed or generated in a hierarchical object structure containing nodes (joints) and connecting segments (bones). Compared to earlier used simple biped structures, the complexity of the skeleton was increased to 24 nodes (Fig 1). A change in posture is represented by a combination of rotational transformations in the joints, resulting in more complex spatial transformations of the hierarchically ordered limbs then. The task to be solved is then to calculate a “naturally looking” surface deformation in all mesh areas that are located close to the concerned skeleton nodes.

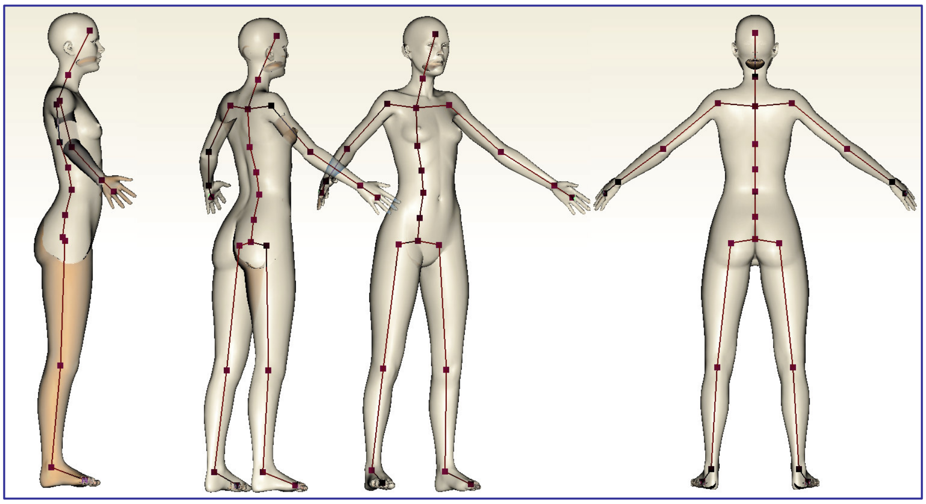

Fig. 1: Mesh deformation results for more complex motions, including hierarchical joint

It has to be stretched, that in reality the body surface, of course, deforms under the direct influence of subjacent tissue (muscles, fat tissue and sinews) and not just from skeleton motion. A complete modeling of the inner body structure, though, was initially excluded for expense and performance reasons. In our target application visual realism, simple-to-apply parametrization and transferability (to different body models) are of first priority, absolutely realistic (in the physiologic sense) deformation modeling is not required here. On the other hand, straight geometric free form deformation models (FFD) used in CAD in most cases turn out to be not adequate for realistic human body modeling, because of “too much regular” results (a “hosepipe” effect, i.e., when modeling a knee bend). Anyway, a non-physical, non-physiological deformation model with good performance was looked for, that would solve the task more sufficiently. We found that compact support radial basis functions (CSRBFs) may provide the desired results.

2. Method description: Compact Support RBFs for joint flexion

Compact support radial basis functions (CSRBFs) represent a mathematical (non-physical) approach. CSRBFs model deformations by interpolating displacements between source and target points. But different from thin-plate spline based methods or multiquadratics CSRBFs provide a local surface deformation effect which is determined on the one hand by a landmark set (free, empirically adjustable in position and number) and a global control parameter for scaling their spatial influence on the other. Further, it is possible to adjust deformation behaviour by utilizing different CSRBFs and by adjusting the scaling parameters. Under practical and implementational aspects, CSBRFs provide a number of advantages like linear growth of calculation expenses and the possibility of parallelization.

2.1 Theory

CSRBFs relate to a set of choosen or defined landmarks which may be but must not be located on a given surface. Denoting q and p for two sets of lets of landmarks both with the same cardinal number n with q representing a source and p representing a target position. Then, the displacements u for points x are:

$$u(p_i) = \quad (q_i - p_i), u(x) \quad = \sum_i \alpha_i R(\|x - p_i\|), \quad i = 1,...,n \tag{1}$$

where $R\ (\cdot)$ denotes a RBF.

Let K denote the $n \times n$ matrix given by $K_{i,j} = R(\|p_i - p_j\|)$. For any CSRBF, R, K is positive definite, and K is guaranteed to have an inverse therefore and the coefficients α can be calculated by $\alpha_i = K^{-1} q_i$.

In our application, we use a so called Wendland function, which represents an important class of CSRBFs constructed from piecewise polynomials. This kind of radial basis function was first introduced in 1995 by H. Wendland from Goettingen university [3].

For a specified dimension $d > 0$ and smoothness parameter $k \geq 0$ there exists a unique Wendland function, $\psi_{d,k}(r) \in C^{2k}(\Re)$ which is positive definite on $\Re^d$ and has a polynomial of minimal degree $(d/2) + 3k + 1$.

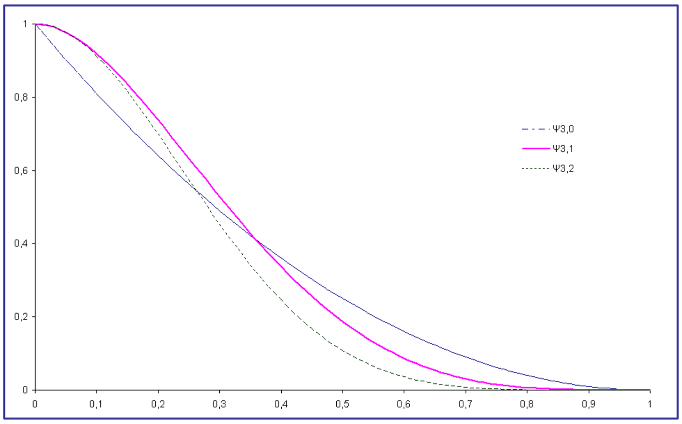

Fig. 2. Examples of Wendland CSRBFs.

In [3] three examples of such functions for $d = 3$ are given as:

$$\psi_{3,0}(r) = (1-r)_+^2\ ,$$

$$\psi_{3,1}(r) = (1-r)_+^4 (4r+1) \quad \text{and} \tag{2}$$

$\psi_{3,2}(r) = (1-r)_+^6 (35/3r^2 + 6r + 1)$, where $(1-r)_+^l = (1-r)^l$ for $0 \leq r \leq 1$ and 0 otherwise.

Plots of these functions are shown in fig. 2. As apparent, the represented functions differ in derivative properties and their behavior when approaching $r \to 0$. In applications these differences will result in degree of continuity. The examples in the present paper were calculated using $\psi_{3,2}$ from (2).

Generally, the behaviour of CSRBFs can be controlled by a locality parameter and by the choice of the particular function, with smoother, more nonlinear deformations provided with $k > 0$.

The global effect of ψ increases with a spatial support parameter, $a > 0$. The CSRBF is scaled as $\psi_a(r) \equiv \psi(r/a)$, and its mathematical properties are not affected.

For more profound and detailed information about Wendland functions and CSRBFs we refer to [3] [4] and [6].

2.2 Applying CSRBFs to joint flexion

In order to apply CSRBFs to our 3D-deformation task of human bodies we assume that the “skin” is to be deformed in a restricted area Ω around the current articulation point in a nonlinear way, while the surface outside that area (“rest skin”) is just moved together with its corresponding bone.

At first we place a sufficient number of source landmarks evenly onto the border of Ω, that means, directly on the surface mesh. Target landmarks represent the new positions of the source landmark set after the intended transformation. To ensure local surface continuity in the border neighbourhood, corresponding target positions for this set of landmarks are calculated directly by spatial rotation around the required angle. The more landmarks are placed at the border of the deformed area, the more unremarkable and continuous the changeover between deformed surface and the “rest skin” appears.

In order to avoid the formation of ridges and “lumbs” in the peripheral regions and to improve the smoothness of the resulting surface, it proves to be useful to place a second row of landmarks not directly at, but in a relatively small distance to the border of area **Ω**.

Finally, in the case of need, particularly in case of bigger deformation angles $\boldsymbol{\varphi}$*,* a third group of landmarks can be placed freely into critical regions of **Ω**. The target landmark positions of these subset may differ from the straight calculated transformation result. It can be used for a “local surface design”, intending to adjust or to fine-tune the result to a physiologically reasonable paradigm.

Number and distribution of supplied landmarks influences the surface (skin) behaviour during joint motion. Higher density of landmarks allows to reduce the spatial support parameter α in the used CSRBF.

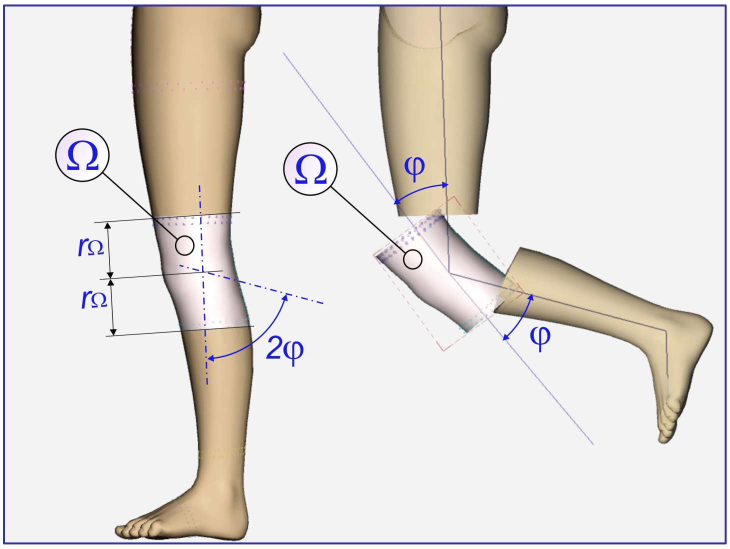

Fig. 3: process illustration with variable indentifiers

In many particular cases it is reasonable to distribute an intended flexion to both included surface parts, even if physiologically one of them remains in it’s initial position. For example, lifting the forearm may be considered solely as an issue of this limb and not including the upper arm. If the complete tension (represented by position differences between source and target landmarks) is applied to only the lower half of the deformation area, the resulting deformation will be less satisfying than if the whole area is deformed.

2.3 Examples of local CSRBF application

To achieve the better result, an interim clipping and rotation of area Ω may be helpful (see Fig. 3). Hence the deformation will be distributed between both surface parts. Initially, all borders will be approximately the same degree of displacement, after deformation all borders will coincide again.

Let’s consider the case of a knee joint motion simulation in detail. We perform it with a female 3D mesh model generated by Poser® software [5]. The initial posture is standing upright with straight legs. The task is to let the model lift one of her feet backwards, performing a flexion of angle $\boldsymbol{2\varphi}$.

We define the area Ω to be deformed by inserting two planes which we position perpendicularly to thigh and shank bones, cutting the “skin” surface at the distance r_Ω from centre O (fig. 3). For convenience, the value of r_Ω is chosen large enough to ensure that the resulting border lines of area **Ω** will not intersect after the intended flexion.

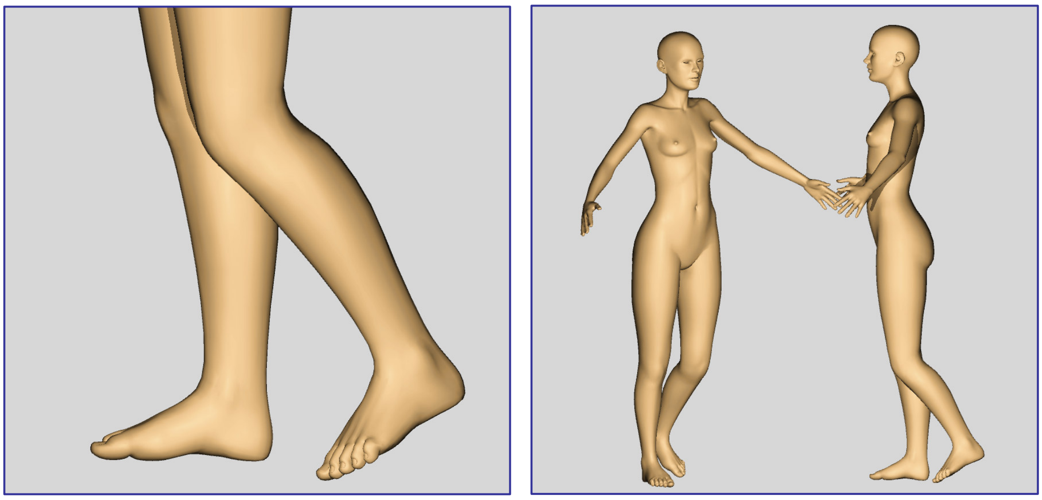

*Fig. 4: Results for simple knee bend for 2**φ** =30°*

Next, source landmarks are distributed evenly at the two outer border lines of Ω: We place two landmark rows at each border line, one row directly at the border and another in a chosen small distance. Each of the four rows we limit to 30 landmarks, altogether 120 points. One more single landmark we put coinciding with the articulation point of the knee.

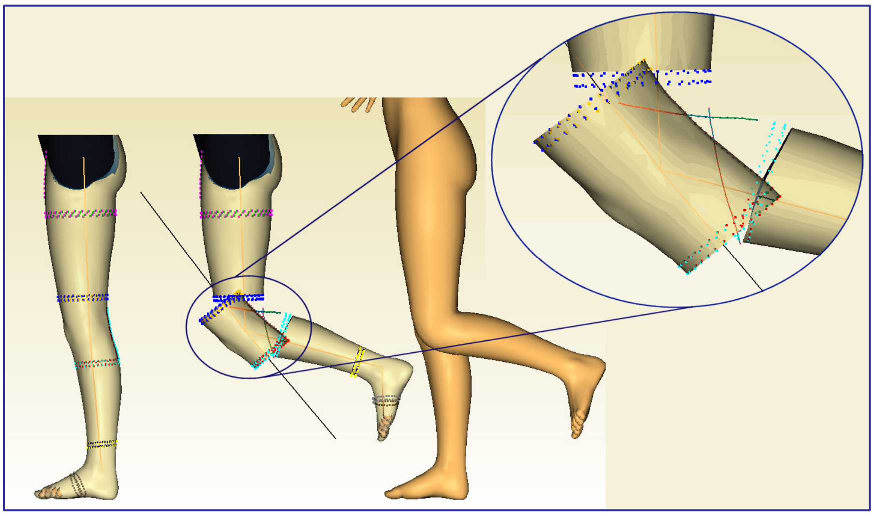

*Fig. 5: More significant bends (here 2**φ** =70 °) require additional landmarks in the hollow of the knee which are distributed at source and target curves*

Target landmarks are calculated simply by means of the transformation matrix which is given for the desired rotation of the corresponding bone (2φ). In an intermediate step, the clipped out area **Ω** together with all landmarks is rotated around the articulation point, so that corresponding source and target landmark positions of thigh and the shank form equal angles φ. We calculate the positions of all included mesh vertices applying a Wendland CSRBF. An appropriate parameter a was determined empirically: $a \approx 2{,}4 r_{\Omega}$. Results of the deformation for φ=15° are shown in Figure 4.

If $\boldsymbol{\varphi}$ is chosen >15°, it becomes necessary to add further landmarks in order to form the inner surface of the flexion area, in this case, in the hollow of the knee. We use seven additional landmark pairs as depicted in fig 5. Source landmarks are placed evenly distributed on a vertical cut through hollow, forming a “source curve”. The position of the corresponding target landmarks was found experimentally, they where placed to slightly different positions until an acceptable form of the flexion was reached. , However, the leading rule was to place the target landmarks on a spatial curve representing the desired form of the “source curve” after deformation. In the depicted case a could be decreased: $a \approx 2{,}0 r_{\Omega}$.

2.4 Applying CSRBFs to other body form adaptations

Beside simulation of motion and flexion, appropriate deformation models are required for the task of adapting human 3D models to individual measurement or size table data. Size tables contain numbers like chest or hip girth, but no information about curvature and form. It is obvious but also confirmed by a number of studies, that with a given body model, simple curve scaling does not comply with reality for growing / shrinking girth measures. Finally, an unlimited number of different body forms may correspond to one and the same chest measure. On the other hand, it is possible to derive statistical regularities (rules) for the dependence between size number and curvature (at least in a certain region or part of population) from statistic measurement data.

Available “real-live” data provided by our body mesurement solution BodyFit 3D [7] [8], which is able to measure predefined cross-sections selectively, can be used for such investigations. Fig. 6 shows a set of 30 by measurement acquired female chest measure lines and the corresponding, parametrized avarage spline curve. All of them are standard size 90 (including measures between >88 and <92 cm). With regard to avatar modelling, this opens a way to adapt initial body models to a realistic and statistically well-founded form, coevally providing correct proportions and measures complying with size tables.

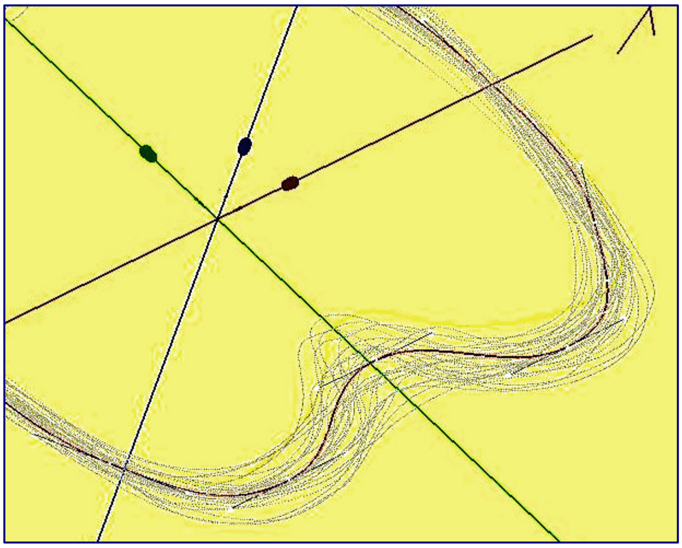

Fig. 6: Determination of spline curves, describing a statistically well-founded curvature for standard table sizes from measured data (measurement see [7])

Of course, it is also reasonable to use the described above CSRBF method for local form adaptions of this kind, if simpler rules (scaling functions) prove to be insufficient. The same applies for other local body type adaptations (i.e. shoulders, muscle strands ect.). However, both landmark field distribution and CSRBF parameters for such operations will be completely different from the described joint flexion task above and can hardly be reused for other (different) body regions.

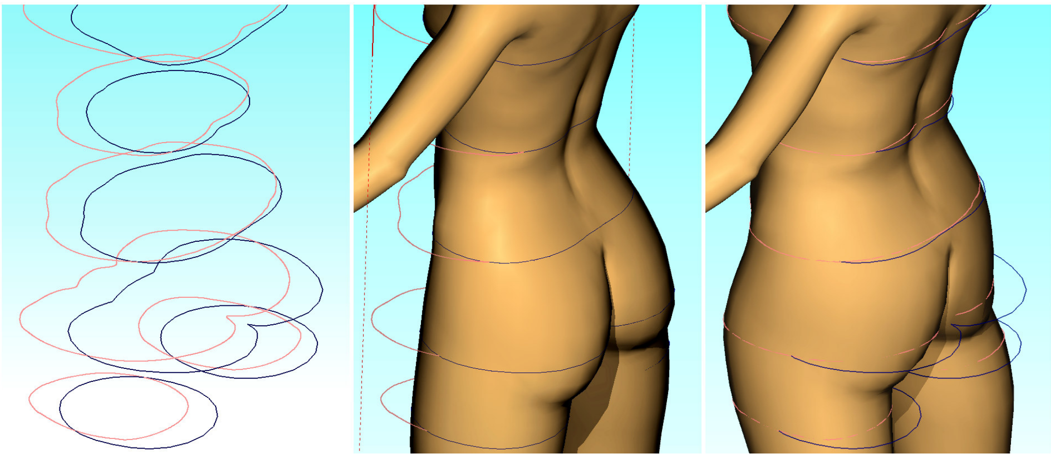

*Fig. 7: Results for static form and posture adaptation by **CSRBFs.***
left: blue lines represent cuts through a basic avatar mesh, red lines are measured [7] curves.
middle: basic (source) mesh model
right: resulting (target) mesh model after CSRBF application. The deformation changes both size measures and attitude (body type). Here, 30 landmark pairs at each of the displayed cut levels were used

3. Results

Currently, we finished definition and implementation of initial deformation areas and source landmark sets for all skeleton joints, admittedly assuming body models in a certain initial body posture. Using the presented algorithmic approach, the changed outer body form can be calculated automatically on the base of a given skeleton-related motion prescription. In order to avoid mounting-up of instability we currently start the calculation each time from the initial posture, even in case of small rotation steps (i.e. for animation).

Currently we suppose that joint motion of knees, elbows, ankles, wrists, spine and neck is simulated sufficiently in almost the whole reasonable range. Motion in hips and shoulders are more difficult to simulate. For such motions the presented method provides acceptable results only for small $\boldsymbol{\varphi}$ (0°..10°).

The results can be (theoretically infinitely) improved by the use of additional landmarks.

Two examples of more complex deformation of the test model are shown in fig 8. Both models were calculated from the initial posture (standing upright with arms spread out, see fig. 1).

It is easily possible to transfer and to apply the prepared landmark structures and deformation objects to other body models, though it is recommendable to check the resulting deformations in case of significant body type variations. In any case of unsatisfying results it is usually sufficient to edit single positions of existing landmarks.

5. Conclusions

We presented algorithmic software development as well as calculation results for simulation of local body deformation based on a class of mathematical functions named CSRBFs. Our implementation proves the described approach and shows the capability to solve the intended task of non-physiological body deformation modeling. The most characterizing properties are

- locally limited deformation rules
- “soft-tissue-like” behavior
- freedom to influence and design the resulting deformations by editing landmark amount and distribution
- Transferability of implemented body deformation objects to other body models
- Availability of global adjustment parameters
- Theoretically unlimited approximation power (improvement potential)
- Low and linearly growing calculation expenses
- Capability of multithreading / parallelization.

In continuation of the presented work we plan to improve the implemented landmark maps and to enlarge the landmark object list to further body regions for particular adaptation tasks. We aim to provide a set of customizable 3D avatars for applications in textile design and ergonomics.

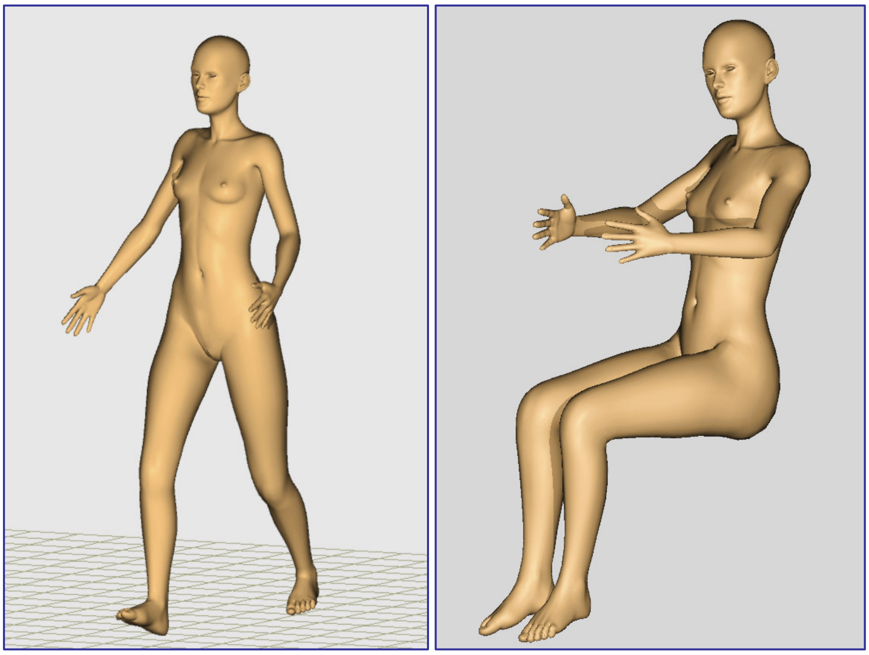

Fig. 8: Mesh deformation results for more complex motions, including

In the presented paper we did not argue with motion design, joint limitations and sources of motion data. For non-specialists in animation it appears to be difficult to design realistic body motions just with PC keyboard and mouse. Realistic digital motion descriptions can be obtained by means of motion tracking measurements. In continuation of our started work towards body animation we plan to use a commercial infrared motion tracking system. It is further planned to supplement these research directions by local real-time surface deformation measurement techniques.

Acknowledgments

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