Crowd Generation Using Morphological Obesity Criteria

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***Abstract*—Generating virtual humans is a great challenge and require the solution of various problems. One of these is deforming the body to create a crowd population for games or simulations. Many visual and morphological criteria have been used such as height, sex, and age but, body mass criteria which is directly related to obesity (and BMI - Body Mass Index) has been neglected. We propose a method that generates variants of a scanned model with different levels of obesity. Fat tissue spread in various ways over the body and our method comply with this at body segment level as well as over different sides of each segment following the data gathered for children. We also propose a two-fold validation method: quantitative and qualitative. To validate generated models, an analysis of models' geometric volume associated with each level of obesity and a questionnaire was presented to 40 experts on Body Perception. We found that size is manageable to perform and assure. On the other hand, experts opinion although favorable to our approach were inconsistent some times: experts were able to identify the fact that base models were from the lower end of the BMI scale used (probably because their head were not deformed) but they could not spot which model was the original one (perhaps because our approach could have fooled them). The data show that our strategy is be able to generate credible virtual humans on various levels of obesity.**

***Keywords*—Character Generation; Crowd Modeling; Deformation; Obesity;**

I. Introduction

Virtual humans are the representation of human shapes and characteristics used in many applications such as virtual reality, simulations, games, training, health, and education [1]. Simulation of virtual humans is a challenge and require solutions to many problems in different areas [2]. Modeling is the first stage to make a virtual human for games or simulations. It can be obtained by manual interactive sculpture or by 3D reconstruction from 2D photos, videos or other technologies (laser scan or RGBD cameras) [2].

Another problem is the deformation of the human body because deformation of bodies allows to generate a diversity of models from a captured or modeled model, such as the older or younger version of a character; slimmer or fatter version; and stronger or weaker version.

Deforming virtual humans are a hard task in computer graphics because of the complexity of the human body [3] and requires data gathered from other areas such as anatomy. Modeling or deforming models of virtual humans should use anthropomorphic data. These data are measurements obtained from human bodies [4]. Anthropomorphic-based models can be used in a vast number of applications, such as animation [5] or health [6], to allow scale the dimensions of the body to easy research and perform analysis, or add/delete morphological characteristics to the model [7]. Deformations applied to virtual humans can be of two types [8]: girth and; length or height deformations. The deformations can be done by direct manipulation of the geometric mesh [9] or driven by control points [10].

Our work deforms a 3D geometric model to create other fatter or slimmer variants, based on general morphological aspects related to Body Mass Index (BMI) and Body Volume Index (BVI) but, instead of using internal organs modeling, only the model mesh is changed driven by anthropometric data.

II. Related Work

Crafted or anthropometric databases of 3D models are used to create other models by interpolation [11] [12] or approximation [13], [14] but, requires a considerable effort to gather a wide variety of 3D scanned bodies - a length, and expertise endeavor.

An approach to driving virtual character generation [15], [16] is through anatomical criteria which can be divided into three different layers [17]: a rigid conception on a real skeleton; the design the muscles; and the deformations based on morphological concepts. Some works developed deformation techniques to volumetric model (that includes internal organs [18], or muscles [19]); others to surfaces models [20] (like the skinning technique [3]).

Some of these approaches use underlying mesh deformation techniques such as Free-Form Deformation (FFD) [10].

Deformation by control points, such as FFD, allows to generate intuitive modifications and can be applied globally (changing all object) or locally (deforming a part of the object). The FFD modification reach is limited by a parallelogram whereby altering one of its control points, and the deformations are transferred to the objects' mesh in within the parallelogram interior.

A. 3D Models in Body Perception

Body Perception is a test used to evaluate the mental figure that people have of themselves concerning the body shape and size, besides of feelings, attitudes, and experiences related to these characteristics, which allows a series of analysis by body perception professional [21]. Body Perception test requires the subject to see a body (his own preferably) at various BMI. Therefore it is an excellent example of the need for a virtual human generation driven by BMI.

3D Models applied in Body Perception can be found to target specific populations such as Blom and colleagues [22] that uses generic models and the head of a person based on European measures. Stewart and colleagues [23] used models based on measures of adult women and men from EUA. Ferrari [24] used 3D models from Brazilian children measures in the software, called SAPECO, which is the basis of sKanner3D. This software shows 3D models at different levels of obesity to apply the Body Perception test.

One way to analyze obesity can be through the Body Mass Index (BMI) [25]. Body Volume Index (BVI) [25] presents another way to analyze obesity.

A systematic literature mapping has shown [26] that existing approaches to crowd generation neglected BMI variations of virtual humans and, no approach whatsoever regardless of the various criteria were found that presents a method to validate its deformation approach.

B. Full Body Capturing

Our approach, named sKanner3D deformation, uses 3D models generated by sKanner3D full body capture module [27]. These 3D models have mesh, rigging and, texture map captured by only one Microsoft Kinect V1 device.

This module allows capturing a real person and creates a deformable model which can receive deformations to create other models in different levels of obesity from the same person. Besides, these models can be used in body perception tests instead of generic models like others approaches.

Other researchers [28] have also dealt with length and height variations of the body mainly, but obesity is not the focus of their work.

III. System Overview

Instead of adjusting a captured model to fit into an existing model of the desired BMI, which would require a search on an extensive database of subjects with a variety of BMI, our approach applies a fattening/slimming function to the full body captured model. These functions were gathered by using the anthropometric data of a group of subjects which growth/shrinking was analyzed per body segment and differently to each side of the segment.

The overview diagram of sKanner3D deformation module is shown in Fig. 1. In brief, the sKanner3D deformation module generates a predefined number of 3D models, based in the 3D model got from the sKanner3D capture module [27], by fattening or slimming functions. First, for each segment of the body, an FFD grid based on the vertices that are influenced by own bones and are aligned to the bone center and rotation is created. Body segments deform according to an adjustment defined is a file called “weight_vertices.csv”. Next, a deformation factor is applied in the FFD grid taking into account different growth behavior to the sides of the grid, according to a configuration file “ffd_sides.csv”. With all segments deformed, the total volume of the model is verified against the expected margin of error. Otherwise, a correction of the deformation factor is done by increasing or decreasing it.

TABLE I. Reference Position Of The Captured Human Model

Reference position	Criteria
1	BMI $<$ 14
2	BMI $>=$ 14 and BMI $<$ 16
3	BMI $>=$ 16 and BMI $<$ 18
4	BMI $>=$ 18 and BMI $<$ 20
5	BMI $>=$ 20 and BMI $<$ 22
6	BMI $>=$ 22 and BMI $<$ 24
7	BMI $>=$ 24 and BMI $<$ 26
8	BMI $>=$ 26 and BMI $<$ 28
9	BMI $>=$ 28

The sKanner3D deformation module generates another eight models, fatter or slimmer. This module is done in the Blender tool through a python script. The inputs of the system are the weight, size, two CSV files (with deformation factors) and, the types of output. The size and weight are used to calculate the Body Mass Index (BMI) of the person’s captured model and so to find the reference position among the nine obesity group, as shown in Table I. For instance, if subjects’ BMI found to be 18, it falls into ref 4, and then sKanner3D will produce three slimmer models and five fatter models. The output of the system can be a video, an image or the file of deformed models.

A. Deformation Factors

The deformation factors file has the names of the body segments and the fattening or slimming factor, based on the proportions between adjacent groups of obesity extracted from SAPECO’s models. These proportions were calculated considering the radius from the anthropometric girth measures taken from caucasian Brazilian children.

Besides input information by sKanner3D users, the module also inputs:

- A table with the minimal weight of vertices to each segment which indicates what vertices are used to be as references to create FFD grids;
- A table with direct influence on FFD which defines how the deform factor is applied to the sides (front, back, lateral sides) of the body segments (Table III);
- A table with the total volume expected for each level associated with that BMI (Table IV).

To generate other models by applying the deformation, sKanner3D uses girth measures, obtained from Brazilian children from 7 to 10 years old [24]. To calculate the deformation factor, first, the radius from the girth measure is identified using (1), for each group and segment. With the radius, the deformation factor is calculated by growth variation among the adjacent groups by using (2). For example, to calculate the deform factor of chest fattening from group 1 to group 2 in Table II, represented by id ‘1-2’, the chest radius of group 2 is divided by the chest radius for group 1.

$$radius = girth \div 2\pi \quad (1)$$

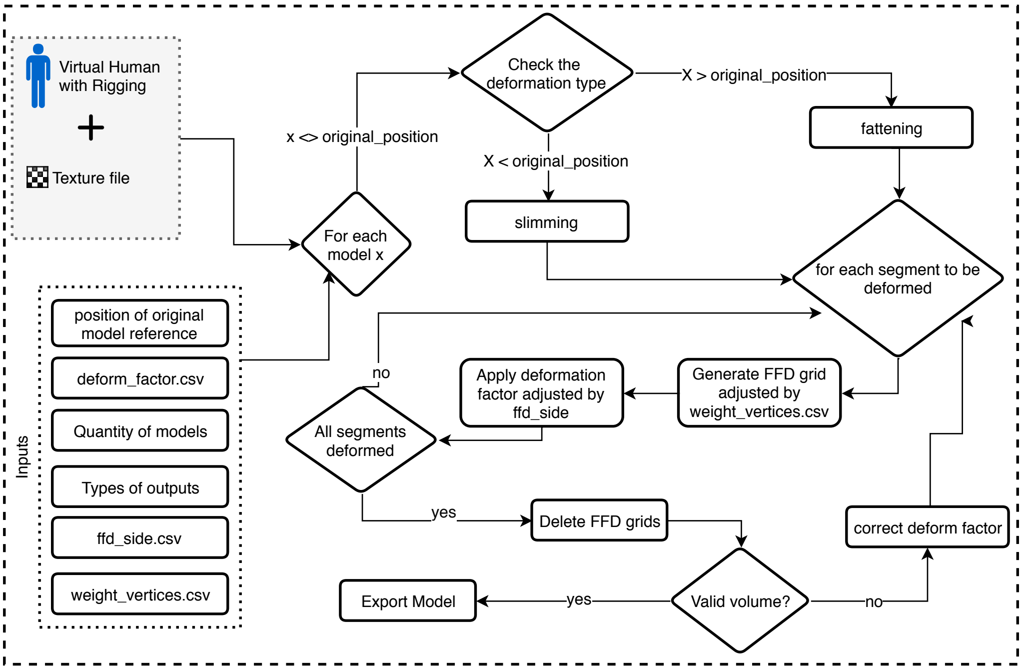


Figure 1. sKanner3D deformation module.

TABLE II. Example Of Deform_Factor.csv

id	thigh	shin	chest	hips	upper_arm	forearm
1-2	1,038	1,093	1,019	1,017	1,055	1,020
2-3	1,059	1,073	1,066	1,052	1,106	1,022
3-4	1,079	1,123	1,028	1,061	1,050	1,029
4-5	1,034	1,003	1,006	1,047	1,091	1,006
5-6	1,021	1,028	1,027	1,028	1,070	1,036
6-7	1,034	1,068	1,064	1,051	1,061	1,021
7-8	1,095	1,049	1,024	1,021	1,058	1,012
8-9	1,061	1,036	1,039	1,048	1,066	1,049

$$growthVar = radiusBMImajor \div raidusBMIminor \qquad (2)$$

B. FFD alignment

The skeleton of the model divides the geometric mesh into groups of vertices (this is the effect of the rigging process obtained by the sKanner3D capturing module). The FFD technique is used with a grid $UxVxW$ of $3x3x3$ size, totaling 27 control points which deformation is based on BSpline curves to apply the deformation factor in the segments of the model. The minimum, maximum and central points of each group of vertices were mapped to generate the grid in a suitable size and position and creates the FFD grids. Another important point is the orientation of the FFD grid concerning the bone angle associated with the body segment. Fig. 2 shows a FDD grid and its application to a model.

A problem found during the generation of the FFD grid using the vertex groups was that a vertex could receive the influence of one or more bones and generate an FFD grid which also changes the positioning some of the vertices of the chest. For instance, one vertex has information about the

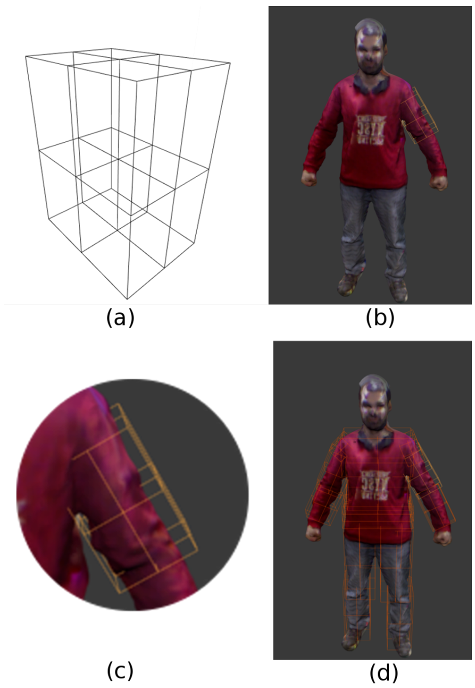


Figure 2. FFD grid generation: a) 3x3x3 grid; b) FFD grind in an upper arm; c) zoom of the FFD grid; d) all FFD grid superimposed to the model.

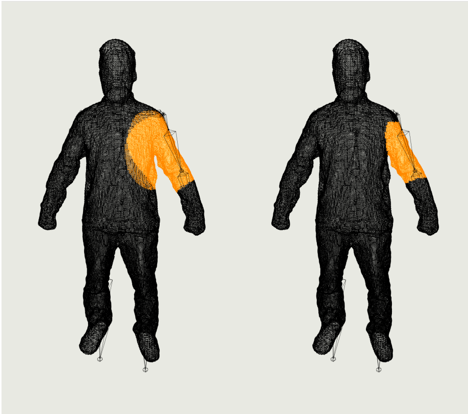


Figure 3. Vertex groups: at the left all vertices of the upper arm is shown; at the right the vertices with a weight of 0.34 is shown.

TABLE III. SAMPLE OF FFD_SIDE.CSV

id	thigh	shin	chest	hips	upper_arm	fore_arm
front	0.30	0.30	0.45	0.45	0.45	0.45
back	0.45	0.45	0.30	0.30	0.30	0.30
left	0.22	0.22	0.22	0.22	0.22	0.22
right	0.22	0.22	0.22	0.22	0.22	0.22

influence weight of a bone which can be 0, no influence, to 1, full influence. Fig. 3, for example, at the left, all vertices influenced by the upper arm FFD grid are shown and, at the right, the vertices influenced when the weight of the FFD grid used is 0.34. Thus, to generate FFD grids in suitable dimensions, there is a file configuration that weights the vertices present in the vertex group for a bone. The weight of 0.34 to the upper and lower arm and zero for the other parts of the body was obtained empirically.

With a proper FFD grid, form factors are applied with an adjustment of a direct influence that tells how much of the factor will be applied to a predetermined direction for each body segment. The direct influence on FFD allows us to apply the factors of deformation differently because the body parts grow, or shrinks, in a different way on its sides. For example, at the chest area, the frontal side grows more than the lateral sides (left and right) and with a smaller influence in the back. In Table III it should be noticed that the FFD grid of the chest is influenced more on the front side than at the backside and consecutively less in the left and right side. The deformation factors were gathered empirically to all sides following the criteria that body sides that are closer to bone structures deform less than those which are closer and supported by muscles for instance. After many tests, Table III presents all pertinent values to keep the coherence of the model in the fattening/slimming process.

C. Internal Validation

The volume of two adjacent SAPECO's models was used as a reference, to validate the deformation, as well as the generated model. The difference is compared to the expected

TABLE IV. PERCENTAGE OF VOLUME GROWTH FOR ADJACENT GROUPS OF BMI FOR FATTENING FUNCTION

BMI Group	Expected Volume Growth
1-2	5,7049%
2-3	9,2554%
3-4	7,5607%
4-5	5,8653%
5-6	5,5567%
6-7	8,5859%
7-8	9,6280%
8-9	6,8490%

volume growth, with a margin of ten percent error. This margin of error is necessary because each 3D model (and human) can have a distinct form and volume for the same BMI [25]. In case this margin of error is not achieved, a correction in the deformation factors is calculated then, FFD grids are recalculated and the corrected factor applied to create the appropriate model.

The volumes expected growth are shown in Table IV and was calculated based on the volume from nine SAPECO's model using a technique by Jorstad and colleagues [29]. For example, line 1-2 shows the increase of volume in the fattening process from model 1 to model 2 where the growth of 5,7049% is expected.

With the expected volume inside the margin of error, the model can be exported to the file type chosen which contains a geometric mesh of the model (that can be used in the majority software of the solid modeling), an image or video format.

IV. EXPERIMENTS

Two experiments were performed to analyze the quality of 3D models generated by sKanner3D.

The first analysis is a two-folded quantitative experiment using volume as a criterion for validation a deformation in a SAPECO's model A create a model B, and this model is compared to the actual SAPECO's resulting model. Another test uses models for children scanned from one RGBD camera (Microsoft Kinect v1) to see if they fall into similar volume ranges.

The second is a two-folded qualitative experiment: a visual analyses of applying sKanner3D to an extreme BMI SAPECO's model and; a questionnaire to body perception experts, who evaluated the 3D models of children created by sKanner3D deformation module.

A. Quantitative Experiment

Fig. 4 shows the volume validation of the generated model. In this test SAPECO models and scanned children are used, and it seeks to evaluate if the deformation of sKanner3D is equivalent to a known result. Then, for each generated model a log with a final volume is registered, and a separate analysis of SAPECO and children models is done.

1) SAPECO's Models: This test seeks to analyze nine known models to see if the sKanner3D can produce models close to the known ones, in terms of both appearance and volume of the geometric model. An artist-designer produced SAPECO's models following anthropometric measurements taken from a group of children of a certain BMI. Notice that when the BMI of a person increases it also increased his volume. For each known model another eight models were generated, so each group has nine models considering the original one. Fig. 4 shows at the top the variation of volume found when sKanner3D is applied to the SAPECO models. It can be noticed that the error in volume is more prominent in the extremes, but the volumes were generated inside the margin of error.

2) Children's Models: This quantitative experiment was done with the 3D models from scanned children to evaluate if skanner3D keeps the volume coherence among the groups of models at the same BMI class as SAPECO's and thus generates credible models. The models of 4 children were scanned and their volumes compared to SAPECO's. It can be verified in Fig. 4 at the bottom that models generated by sKanner3D were compliant to SAPECO's within the defined margin of error.

The children's models in Fig. 4 shows the average of the variation increase in volume about the first model. Notice that the volume growth lay in the lower range of error (10%). Observe also, that the volume variation was near to the SAPECO's models to slimmer models. This volume variation can be explained because the groups of BMI children were: one child of group 1, two of the group 3 and one of the group 4. These data suggest that the farther from the original model, the bigger the error but still within the margin the error. The error is difficult to avoid because although weight change seems to follow a linear behavior, that is not the case among each body segment as shown in Table II. Overall, these quantitative tests show that sKanner3D deformations were able to produce SAPECO's or children's model at similar ranges.

B. Qualitative Experiment

1) Deforming SAPECOS's Model: The top line of Fig. 5 shows the original SAPECO's models for a boy; in the bottom line, the latest model is an original model, and sKanner3D generated the others. It can be observed that generated variations can reproduce a variation close to the corresponding model in the same obesity level from SAPECO, in terms of its general morphology. However, because SAPECO's models were made manually and, have a greater smoothness in their contours, the slimmer models presented muscular characteristics and some imperfections in the arm. It can also be noted that the sKanner3D deformation module ignored the shorts and hair of the model because it is a geometric mesh separated from the body of the model. In manually generated models, it is normal to generate separate geometric meshes to customize the model, so for sKanner3D to deform these objects, it is necessary to associate them vertices to some skeletal bones. In the case of shorts, for example, the vertices must be attached to the hip bone. Thus, this situation only occurred because of the way the meshes were generated for the SAPECO's models. Fig. 6 shows the result of sKanner3D for scanned real children, where the original models are number 3 and 1. It can be observed that the validation by volume presented for scanned models seems to be a useful metric to generate models which can be used in Body Image area.

2) Experts opinions: Brazilian experts in the Body Image Perception area were consulted to analyze the quality of the generated models. To find these experts, a search for scientist articles in the Google Scholar search engine (https://scholar.google.com.br/) was made with the keywords: "body image" or "body perception" (but in Portuguese). The results were analyzed to see if the article was, in fact, about body image. If positive, the emails found in the articles were collected to send the questionnaire.

In total, 648 distinct e-mails were collected to which a link to an online questionnaire was sent. Off these, 178 returned as an invalid email; therefore, off 470 valid e-mails 40 answered the questionnaire. On average the expert took 9:43 minutes to complete the questionnaire.

After a pilot questionnaire sent to some experts, it was improved to a questionnaire that contains 3D models from 2 children. To each child, nine models were shown (1 original model scanned and eight generated by sKanner3D deformation) as image and a 360° video of each model so that subjects could analyze them and answer the following:

- P1 - Which of the 3D models presented in the video and image do you believe is the real/original child? (the others were generated by computer). Models were placed randomly regarding BMI class;
- P2 - Again, please, according to the models presented in the video and image, which model do you think is the real/original? (the others were generated by computer). Models were placed sequentially regarding BMI class;
- P3 - Considering the model as the slimmer of the sequence, it can be said that the body shape (proportions among segments, mainly) is coherent. For this statement, check your degree of agreement;
- P4 - Considering the model as the intermediate level of the sequence, it can be said that the body shape (proportions among segments, mainly) is coherent. For this statement, check your degree of agreement;
- P5 - Considering the model as the fattest of the sequence, it can be said that the body shape (proportions among segments, mainly) is coherent. For this statement, check your degree of agreement;
- P6 - Considering the 3D models presented, I see that they represent models of children with variations to their weight. For this statement, check your degree of agreement;
- P7 - The body variation (proportions and morphology between front/back) is coherent. For this statement, check your degree of agreement;
- P8 - The rotation of the models in the video, allows me to analyze the body shape better. For this statement, check

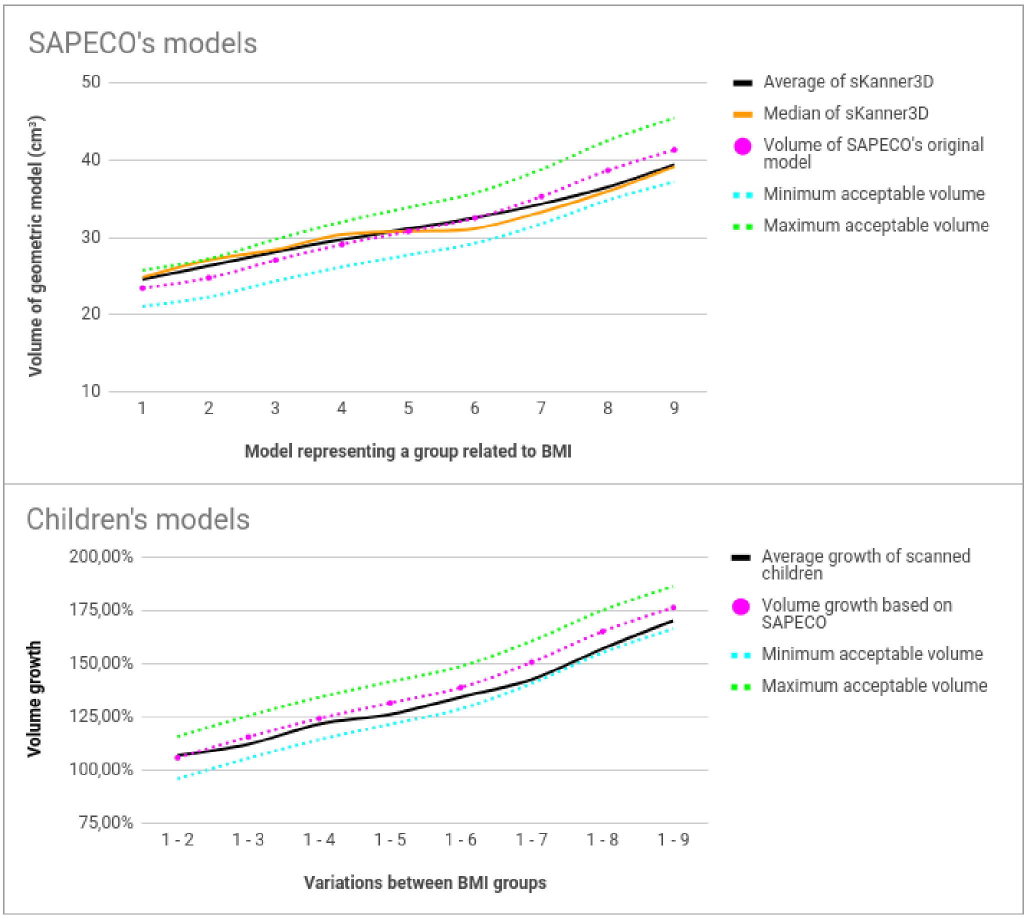


Figure 4. Quantitative analysis between models generated by sKanner3D from scanned children and from SAPECO's models.

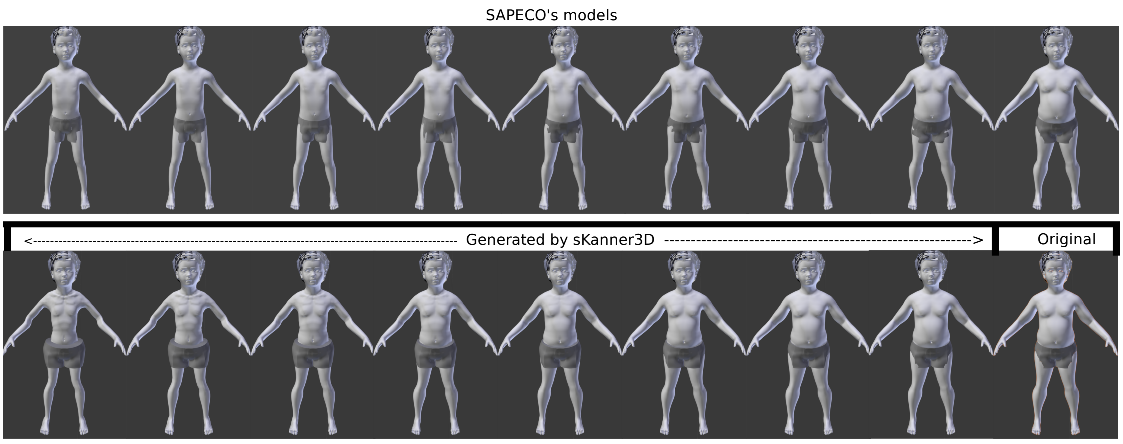


Figure 5. SAPECO's models of a boy and models generated by sKanner3D.

your degree of agreement;

- P9 - If you want, leave your comments about the 3D models presented.

The questions P1 and P2 aim to analyze if subjects can differentiate between captured from generated models. In P1 the models are shown in random levels of obesity, and in P2 the models are shown in continuous levels of obesity because we wanted to see if the order influences the answer. The questions from P3 to P5 aim to analyze extreme models and the intermediate models. Questions P6 and P7 perform a general evaluation of the models and question P8 analyze the way the models are presented. Lastly, question P9 collect comments

Figure 6. 3D Models generated by sKanner3D. Highlighted models are the originally scanned model of the child.

about the perceptions of the subjects about generated models.

The 3D models for two female children with different levels of obesity were used. To each child, questions P1 to P9 were presented with a reference video and an image for all nine models. For questions P1 and P2, the models of the first child were shown in random mode and increasing sequence. The models for the second child were shown in the random mode and decreasing sequence. For questions P3 to P8 a Likert scale of 5 points (from 1, totally disagree, to 5, totally agree) was used. Demographic data collected about subjects were; sex, background, educational degree, years of professional experience and age.

Subjects were 32 women and eight men, their background: Physical Education (30%), nutritionist (30%), psychologist (15%), physiotherapist (12,5%), teacher (7%) and nurse (2%). The majority (47,5%) indicated a complete Doctorate followed by 15% of incomplete Doctorate and complete Master's degree, each. Subjects presented an average of 15,25 years of professional experience (std dev. 10.33) and an average of 39 years old (std dev. 9.8).

For questions P1 and P2, the data suggest that the majority of subjects choose as original model another that is not the correct one which suggests that the models generated by skanner3D have convinced the subjects by the processes of fattening or slimming, i.e., sKanner3D was able to deceive the subjects, see Table V. For P1 (random) and P2 (sequential) questions, the data was sorted for both tests by BMI and correlation analysis (Pearson) were done: for P1, r=0.84, and p=0.005; for P2, r=0.91 and p=0.000. These results show that there is a significant and robust correlation between responses and BMI. It denotes that there was a tendency to reject the fatter model either in P1, or P2. Therefore, showing the models in random or sequential mode did not interfere in the choice.

TABLE V. ANSWERS TO QUESTIONS P1 AND P2 ABOUT CHILDREN MODELS (N=40)

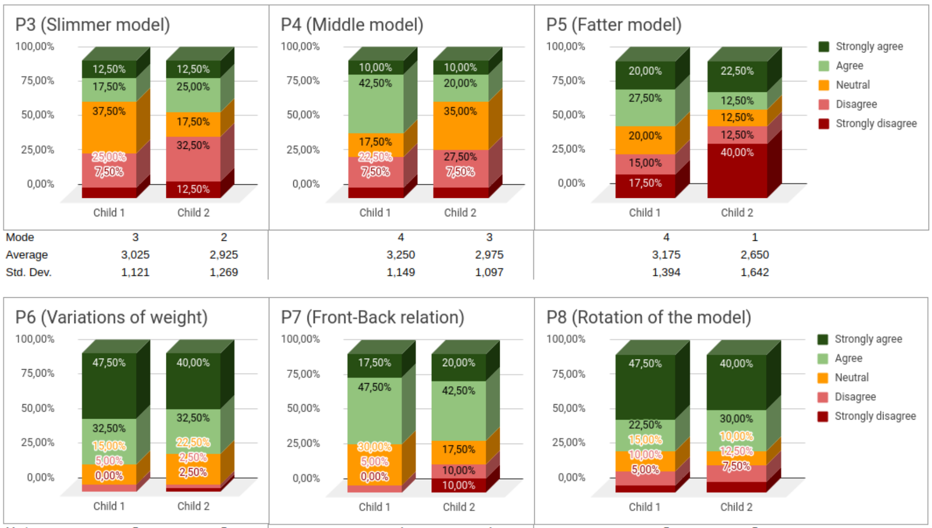
Model	Original model (reference BMI of the model)	Correct answer	Incorrect answer
Child 1 in P1 (random placement)	Model 9	10,00%	90,00%
Child 1 in P2 (increased placement)	Model 3	12,50%	87,50%
Child 2 in P1 (random placement)	Model 6	30,00%	70,00%
Child 2 in P2 (decreased placement)	Model 9	7,50%	92,50%

The results for questions P3 to P8 are presented in Fig. 7. Question P3 (slimmer) shows a good acceptance of the slimmer version of child 1, but, for child 2, 45% disagree of the body coherence of the models. It must be stressed that child 2 in P3 is the original model for child 2. It might suggest that the model generated by sKanner3D was much more believable than the original model.

Fig. 8 shows how answers were distributed over the models after being put into order both for P1 and P2 (P1 is sequential, but P2 was random), for child 01 and child 02. It can be seen that only for child 02 in P1 there were a significant amount of expert answers assigned to it. To all other situations, experts did not select the actual (original) model.

The intermediate model int the BMI scale, in question P4, presented a high level of agreement to child 1, but it did not to child 2. In P5 (fattest), there was a good level of agreement for child 1, more than 50%, but there was more than 50% disagreement for child 2. For this question, The disagreement among subjects can be justified by the clothes used by child 2. Because it is loosely worn, it has distorted the image of the fatter model.

Questions P3, P4 and P5 in Fig. 7 show subjects' tendency



	P3 Child 1	P3 Child 2	P4 Child 1	P4 Child 2	P5 Child 1	P5 Child 2
Mode	3	2	4	3	4	1
Average	3,025	2,925	3,250	2,975	3,175	2,650
Std. Dev.	1,121	1,269	1,149	1,097	1,394	1,642

	P6 Child 1	P6 Child 2	P7 Child 1	P7 Child 2	P8 Child 1	P8 Child 2
Mode	5	5	4	4	5	5
Average	4,225	4,05	3,775	3,525	3,975	3,825
Std. Dev.	0,891	0,986	0,800	1,219	1,230	1,299

Figure 7. Results of qualitative experiment questions from P3 to P8.

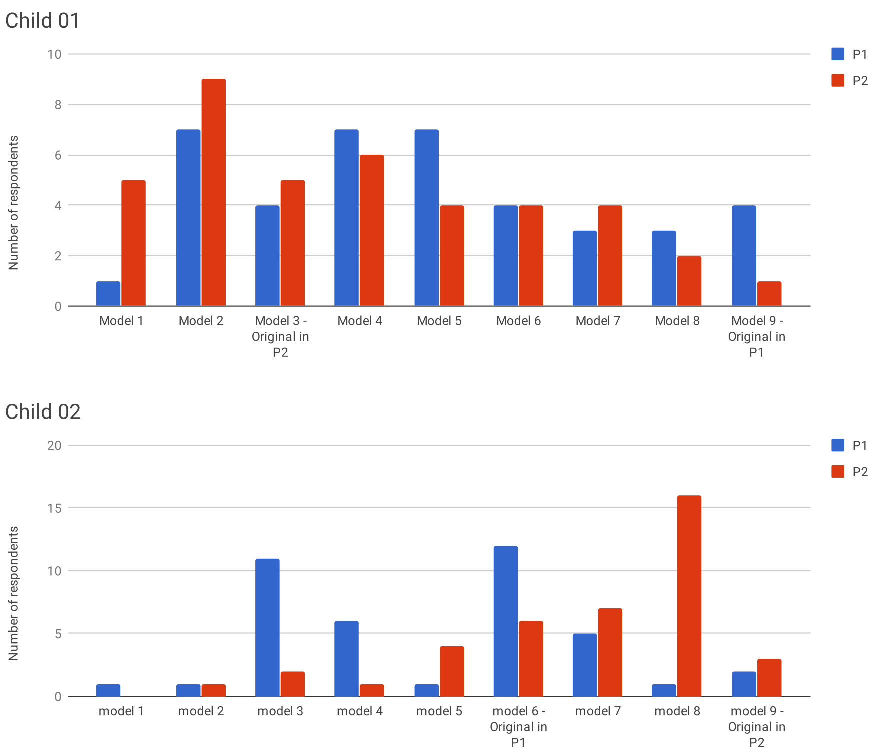


Figure 8. Answer Distribution from P1 and P2 questions.

agreeing more with the models of child one than models of child 2. It can be justified by the type of the clothes that children were using during the scan process and can deceive the perception concerning the weight of the model: for child one, the clothes are more adjusted to the body, and for child two the clothes are loose to the body.

In question P6, it should be noticed that only 5% of the subjects disagreed that presented models of two children represent these children with variations of their weight. In P7, a small percentage of subjects judged that front and back proportions of the children were not coherent. The rotation of the models (P8) to better see the shape of the body achieved only 15% of disagreement for child 1 and 18% for child 2.

Despite the majority of the subjects agreeing to questions P6 and P7 regarding the features of the test to a general analysis, these perceptions did not reflect in questions P3, P4, and P5, that analyzed specific models. This can be justified by comments of the subjects in question P9 that clothes of the child 2 compromised viewing the variations which gave them a feeling of distortion. It must be remembered that traditional silhouettes scale used for Body Image Tests [30], [31], usually take away all the distractors, such as clothes, hair and face details.

Based on these results, it can seem that sKanner3D can generate variations in the level of obesity and morphologically maintain the coherence of body shape. Data show that models generated by sKanner3D were able to fool experts regardless if the models are randomly or sequentially presented, but they presented a bias towards slimmer models. This conclusion can be justified by the fact that we have left head and neck out of the deformation process and that our reference models were both slim ones (BMI class 1 and 3). It can be said that experts somehow spotted model's morphological structure but were not intelligent enough to pinpoint which model was the original one. This part suggests that sKanner3D is capable of generating believable models.

C. Final Considerations

The whole process lasted approximately 4 minutes to scan a person and approximately another 4 minutes to generate eight models from a base model and export them to video and image formats. These values were obtained in a computer with Intel Core I5-4570 processor, 16GB of RAM, 1TB of HD, NVidia GeForce GTX 780Ti 3GB, Microsoft Kinect v1, Windows 7 Professional (64bits) Operating System, and the model mesh with approximately 50.000 vertices.

Existing software allows realistically creating characters for games or simulations but in a manual and time-consuming process that need to be performed every time a new model is required. Our approach automates the generation of obese/slimmer virtual characters in a fast and realistic way that allows Body Perception tests to be performed with someones' own body as a reference model. The only inputs to our approach are age, height, weight and the scanned model (gather from one RGBD camera), although it will only work so far for Brazilian children. We reckon that for games, main character generation need not be that fast, and thus, another more artistic and detailed modeling can be used instead. This project is designed to create a large variety of secondary characters for games and simulations.

Saito, Zhou e Kavan (2015), one of the most realistic approaches so far, used an anatomical model including muscles and fat tissues in order to produce a variety of (obese) virtual humans. However, their work does not contemplate all aspects of the fattening/slimming process because this is different for each person. To extend their approach, it would require a deep understanding of how peoples body respond to the mass gain/loss which still is an open issue of research. Considering the number of muscles and tissues in the body and how these fit into a body, it would probably end up in a massive set of parameters to model the process. It would render their approach intractable for an artist or designer. Therefore, it is a demanding and sophisticated as well as, an incomplete solution. In another hand, to extend our approach, it would require gathering anthropometric data from more real people and a much smaller amount of parameters to control the crowd generation.

V. Conclusion

Generating variants of virtual humans according to some criteria is a wide research field in computer graphics applications sush as games, health, ergonomic among other'. We reviewed the literature and found a gap in generating virtual humans (childern) based on anthropometric and morphological criteria that is related to the obesity of the model - and the process of fattening or slimming.

We have proposed a novel approach to generate virtual humans that are driven by data gathered from a specific population which is them used as parameters to deform the model accordingly but takes into account that each body segment deforms differently in terms of volume as a whole and differently in each direction. These data mimics the way the body responds to weight gains or losses.

The approach was compared to existing models of real subjects using quantitative and qualitative analysis. Quantitative analysis proved that our approach could produce BMI variants of the model that comply to volume variations of the real model. Qualitative analysis enrolled 40 experts in a process to see if sKanner3D produces convincing models. Experts could not tell apart which model was scanned from a real child from those generated by our approach.

The use of anthropometric data is necessary to guide the deformation of each body segment and so, yield a global deformation. Indeed, it was possible to generate 3D models based on nine groups of children with various obesity levels, good enough to be used for body perception tests associated with BMI, among other applications.

The proposed approach is simple in terms of modeling the body structure (does not require modeling internal organs and bones, nor physiological behaviors) and has been shown to produce believable models but it requires extensive anthropometric data which changes according to age, sex, and ethnic group. Unfortunately, the existence of such data is not readily available from medical literature. The lack of detailed data forced an empirical solution for applying deformations over different directions on each body segment.

It is suggested that, in the future, an evaluation questionnaire should include: models with clothes more fit to the body; equal and light clothing for all children; hair tied if they are long; present models closer to more distinct ones; fewer variants being presented to subjects; include a third model near the fattest end of the BMI scale, and there is no need to randomize presentation.

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REFERENCES

[1] D. Thalmann and S. R. Musse, *Crowd simulation*, 2nd ed. London: Springer, 2013.

[2] N. Magnenat-Thalmann and D. Thalmann, *Handbook of Virtual Humans*. John Wiley & Sons, 2006.

[3] A. Aubel, "Body Deformations," in *Handbook of Virtual Humans*. Wiley Online Library, 2006, pp. 140–160.

[4] R. C. C. Vieira, C. A. Vidal, and J. B. Cavalcante-Neto, "Manipulação corporal de personagens virtuais por deformações de medidas antropométricas," in *Symposium on Virtual and Augmented Reality*, 2010, pp. 102–111.

[5] N. Magnenat-Thalmann, H. Seo, and F. Cordier, "Automatic modeling of virtual humans and body clothing," *Journal of Computer Science and Technology*, vol. 19, no. 5, pp. 575–584, 2004. [Online]. Available: http://dx.doi.org/10.1007/BF02945583

[6] N. Werghi, "Segmentation and modeling of full human body shape from 3-d scan data: A survey," *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, vol. 37, no. 6, pp. 1122–1136, Nov 2007.

[7] H. Seo, "Anthropometric Body Modeling," *Handbook of Virtual Humans*, pp. 75–98, 2006.

[8] M. Kasap and N. Magnenat-Thalmann, "Customizing & populating animated digital mannequins for real-time application," in *Proceedings - 2010 International Conference on Cyberworlds, CW 2010*, 2010, pp. 368–374.

[9] A. McAdams, Y. Zhu, A. Selle, M. Empey, R. Tamstorf, J. Teran, and E. Sifakis, "Efficient elasticity for character skinning with contact and collisions," in *ACM SIGGRAPH*, 2011, pp. 1–12. [Online]. Available: http://doi.acm.org/10.1145/1964921.1964932

[10] T. W. Sederberg and S. R. Parry, "Free-form deformation of solid geometric models," in *Proceedings of the 13th Annual Conference on Computer Graphics and Interactive Techniques*, ser. ACM SIGGRAPH '86, 1986, pp. 151–160. [Online]. Available: http://doi.acm.org/10.1145/15922.15903

[11] L. Huang and C. Gao, "Nonuniform Parametric Human Body Based on Model Reuse," in *5th International Conference on Digital Home*, nov 2014, pp. 406–411.

[12] L. Jun, Z. Mingmin, P. Zhigeng, W. Shengbo, and Y. Zheng, "Creating real body model of dressed human based on fat extent of body," *Multimedia Tools and Applications*, pp. 6951–6966, 2015.

[13] A. Feng, D. Casas, and A. Shapiro, "Avatar reshaping and automatic rigging using a deformable model," in *Proceedings of the 8th ACM SIGGRAPH Conference on Motion in Games - SA '15*, ser. MIG '15. ACM, 2015, pp. 57–64.

[14] M. Kasap and N. Magnenat-Thalmann, "Skeleton-aware size variations in digital mannequins," *Visual Computer*, pp. 263–274, 2011.

[15] A. S. Ruela and F. G. Guimarães, "Procedural generation of non-player characters in massively multiplayer online strategy games," *Soft Computing*, vol. 21, no. 23, pp. 7005–7020, 2017.

[16] R. C. C. Vieira, C. A. Vidal, and J. B. Cavalcante-Neto, "Expressive reproduced characters for games," in *2014 Brazilian Symposium on Computer Games and Digital Entertainment*. IEEE, 2014, pp. 210–219.

[17] L. P. Nedel and D. Thalmann, "Modeling and deformation of the human body using an anatomically-based approach," in *Proceedings of Computer Animation 98.*, Jun 1998, pp. 34–40.

[18] L. France, J. Lenoir, A. Angelidis, P. Meseure, M.-P. Cani, F. Faure, and C. Chaillou, "A layered model of a virtual human intestine for surgery simulation," *Medical Image Analysis*, vol. 9, no. 2, pp. 123 – 132, 2005, medical Simulation - Delingette.

[19] S. Saito, Z.-Y. Zhou, and L. Kavan, "Computational bodybuilding," *ACM Transactions on Graphics (TOG)*, pp. 1–12, 2015.

[20] G. Anderson, M. Aftosmis, and M. Nemec, "Parametric Deformation of Discrete Geometry for Aerodynamic Shape Design," in *AIAA Paper 2012*, ser. Aerospace Sciences Meetings, 2012, pp. 1–18.

[21] R. F. Matsuo, M. Velardi, M. R. F. Brandão, and M. L. de Jesus Miranda, "Imagem corporal de idosas e atividade física," *Revista Mackenzie de Educação Física e Esporte*, vol. 6, no. 1, 2007.

[22] K. J. Blom, A. I. B. Rivas, X. Alvarez, O. Cetinaslan, B. Oliveira, V. Orvalho, and M. Slater, "Achieving participant acceptance of their avatars," *Presence*, vol. 23, no. 3, pp. 287–299, Oct 2014.

[23] T. M. Stewart, H. R. Allen, H. Han, and D. A. Williamson, "The development of the body morph assessment version 2.0 (bma 2.0): tests of reliability and validity," *Body Image*, vol. 6, no. 2, pp. 67–74, 2009.

[24] E. P. Ferrari, "Construção e validação de um instrumento digital para avaliação da imagem corporal infantil," thesis, Programa de Pós-Graduação em Ciências do Movimento Humano da Universidade do Estado de Santa Catarina, 2016.

[25] D. Muralidhara, "Come 2020!; welcome body volume index!!; bye bye body mass index!!!" *Integrative Obesity and Diabetes*, pp. 26–27, 2015.

[26] G. C. Silva, M. S. Tavares, A. T. d. Silva, and M. d. S. Hounsell, "Virtual Human Deformation: A Systematic Literature Mapping," in *SLAT - Simpsio Latino-Americano de Jogos* , Ararangua, SC, 2016, pp. 146–153.

[27] M. V. L. Balatka, M. R. F. Silva, G. C. Silva, M. S. Hounsell, and A. T. Silva, "Captura completa de avatares com uma única câmera rgbd," in *Anais do XVI Simpósio Brasileiro de Jogos e Entretenimento Digital*, vol. 1. Curitiba, PR: Sociedade Brasileira de Computação, 2017, pp. 146–153.

[28] K. Baek, Seung-Yeob; Lee, "Parametric human body shape modeling framework for human-centered product design," *CAD - Computer Aided Design*, vol. 44, no. 1, pp. 56–67, 2012.

[29] A. Jorstad, B. Nigro, C. Cali, M. Wawrzyniak, P. Fua, and G. Knott, "Neuromorph: A toolset for the morphometric analysis and visualization of 3d models derived from electron microscopy image stacks," *Neuroinformatics*, vol. 13, no. 1, pp. 83–92, Jan 2015. [Online]. Available: https://doi.org/10.1007/s12021-014-9242-5

[30] T. Sørensen and A. J. Stunkard, "Does obesity run in families because of genes? an adoption study using silhouettes as a measure of obesity," *Acta Psychiatrica Scandinavica*, vol. 87, no. S370, pp. 67–72, 1993.

[31] A. J. Stunkard and T. I. Sorensen, "Obesity and socioeconomic status–a complex relation," 1993.