Exploitation of 3D Body Databases to Improve Size Selection on the Apparel Industry

Sandra ALEMANY*, Alfredo BALLESTER, Eduardo PARRILLA, Jordi URIEL, Jorge GONZÁLEZ, Beatriz NÁCHER, Juan Carlos GONZÁLEZ, Álvaro PAGE
Instituto de Biomecánica de Valencia, Valencia, Spain

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Abstract

Nowadays each clothing company defines its own sizing chart to label the garment. The lack of regulations and the different labelling methods used on each country contribute to have a confusing buying process for the end users in terms of garment size selection. Depending on the brand, the customer selection can vary several sizes. This makes that customers need to try on many sizes to select the suitable one during the buying process. This is one of the main barriers to the growth of the online sales in the fashion market. The high number of returns and their associated costs (e.g. management, logistics and operations) represent an important economic burden for fashion companies.

A large number of technological solutions have emerged in the past years to help buyers in size selection, including commercial technologies to capture body dimensions, to predict the best-fitted size and to provide a fitting visualization. Nevertheless, these technologies have not achieved a compromise between cost, efficacy and accuracy enabling an extensive market penetration. Garment size selection from the anthropometry of the user body could be an interesting approach for e-Commerce. However, the current approaches have not been revealed as the definitive solution. A sizing system based on anthropometry requires the integration of technology and knowledge; namely, the acquisition and processing of the user anthropometry and garment fitting prediction.

There are many alternatives to register the anthropometry of the user: from accurate and expensive 3D body scanners to solutions based on Electronic Consumer Goods (e.g. Microsoft kinect, webcams). Accuracy, accessibility and usability are important requirements of a body measuring system that enables the size selection. The use of 3D body databases to guide the reconstruction of 3D body shape could be an interesting approach to progress in this way. The analysis of large 3D body pools using advanced 3D body shape modelling has also experienced a breakthrough. Research work conducted in the reconstruction of 3D body shapes from body measurements or from only two or three 2D contours using 3D body databases opens the door to the feasibility of having low cost scanners with an acceptable accuracy for size selection.

By contrast, the fitting prediction, understood as the relationship between the body anthropometry and the garment dimensions, has not been studied in depth. The fitting of the garment and the selection of the proper garment size depend on many factors (e.g. style, anthropometry, textile, personal preferences), hence, the use of size charts is not enough to obtain successful results.

The aim of the this paper is to present a proposal of new methods for the development size selection systems based on a 3D body acquisition process using 3D body reconstruction and a multi-fitting approach to predict garment size.

Keywords: Size selection, clothing, 3D body modeling, reconstruction, 3D body databases, fitting

1. Introduction

Today, consumers that buy clothing online base the choice of the size of the the garment on their previous experience and on the size allocation charts typically provided at brands and sellers' websites. A size allocation chart is a table indicating the ranges of the main body dimensions corresponding to each size. Body dimensions measured manually by consumers are not reliable and the ranges of the size allocation charts are not fully clear. It is common to fit into different sizes depending on which dimension is selected to enter the table (i.e. waist girth and hip girth for trousers) and usually there are no indications to make the right size choice when this conflict occurs. This method is neither precise nor interactive enough to provide a suitable size choice [1]. As a result, size tables are not being used by most of the consumers and size selection persists as a major barrier to buy garment online.

* sandra.alemany@ibv.upv.es; http://www.ibv.org/en.html

In this context, the development of new technologies and online services addressed to the selection of the proper garment's size or model for the consumer have been developed in the last two years by Whatfitsme[2], SizeWand [3], Mipso [4], Truefit [5], Zafu [6], Me-ality [7], UPcload [8], Poikos [9], Fitsme [10], Styku [11]. In all of them, the user introduces their data to characterize their fitting requirements. This is the input to predict size, to fit on different body areas for one specific garment or to provide the best models and styles for the body morphotype of the user.

Some of these systems are based on the user's virtual closet to generate matches of garment models between consumers by means of artificial neural networks algorithms. This approach requires large databases of consumers' virtual closets sharing common garment models and sizes, and a training period to set up the algorithms for the new models. Considering the short lifespan of clothing products, these requirements are a major drawback that prevents the scalability of the system and the application to the global sector. Nevertheless, the majority of these systems base the size selection on user anthropometry. Garment fitting depends on user body shape and dimensions [12]. Hence, sizing systems based on anthropometry are a direct method and a more reliable approach because they relate the geometry of the user body and geometry of the garment. Current size selection systems based on anthropometry use different methods to acquire the anthropometry of the user: i) Expensive 3D scanners available on specific points of sale, ii) 3D parametric avatars reshaped with manual anthropometric user data and iii) systems using electronic consumer goods to capture body measures.

Body scanning technologies used commercially for the digital measurement of the human body (laser and white light projection) are very expensive (from 40k€ to 60k€) and limit their application to research purposes and large-scale sizing surveys. A new innovative body scanning based on radio wave technology, conceived for retail applications, able to register body shape with the user fully clothed was released on 2002. This is a less invasive solution for the privacy of the user but still available at a high price for a single user or retailer. The high price of these systems limits the number of points of measure available which is an important barrier for e-commerce applications.

The novel size selection tool developed by Poikos, obtains body measures with a smartphone taking two photographs, a frontal and lateral view of the person. From these pictures, the system calculates key anthropometric measures of the user that can be used for garment size selection. The use of Electronic customer Goods (ECG) for the acquisition of the anthropometry of the user uptakes an important potential market and provides a smart shopping experience.

The weak point of gathering a small number of pictures to extract anthropometric dimensions is the accuracy of body contours. In order to overcome the poor accuracy of ECG, Wais et al. (2011) proposed the use of 3D body databases to guide the 3D reconstruction of the subject body shape [13] captured with Kinect. The errors obtained with these reconstructions were of the same order of the acquisitions made with high precision 3D body scanners. With a similar approach, Saito et al. (2011) suggested a 3D reconstruction of the torso from the frontal and sagittal silhouettes. The shape variability of the torsos was described by using Principal Component Analysis (PCA). Regression models relating the 2D silhouettes with the loadings matrix of the PCA enable the 3D reconstruction. In the same way, the support of 3D databases may be used to obtain accurate results for the calculation of body dimensions from a reduced number of pictures. The feasibility of this method for size selection is presented in the first part of this paper.

The size selection process consists of matching the user anthropometry to garment dimensions. Apart from the application of size allocation charts offered by some apparel industry companies or the size tables provided by different standards, there is a lack of studies published analyzing this relationship.

The second part of the paper presents a study to generate multi-fitting models to predict garment fitting and a proper size selection from the body dimensions of the user. To this end, an experimental study was conducted with 50 female and four garments: two trousers, one blazer and one skirt. Participants were measured using a 3D laser body scanner and a measuring tape for tailoring. Fitting tests were conducted for each garment style to gather, by means of questionnaires, the subjective perception of the user wearing the garment, the fitting preferences, and the suitable garment size. Statistical models were developed to predict the fitting of the key areas and the proper size for the customer with a high rate of success.

2. 3D body shape reconstruction

One of the main drawbacks of the use of 3D models is that a high quality acquisition is costly. Moreover, it can also be unpractical on some settings, for example, in case someone wants to use his 3D model for online shopping. Accordingly there is the need for a low cost alternative which yields 3D models with enough precision for garment size selection and adequate for an online shopping buying experience. Two alternatives based on 3D reconstruction are presented: using 1D measurements or a small set of photographs taken from different angles.

The methods of 3D reconstruction presented in this paper are data-driven, in the sense that 3D model reconstruction is done using range scans and their corresponding measurements. This contrasts with a purely parametric design of a human where no real data is used and where there is the risk of generating unrealistic parameterized models. This means that it is important to have access to range scans databases. Fortunately, more than 150,000 scans have been registered in more than 18 countries, which enable the recreation of anthropometric valid models. The 3D body shape reconstruction work described in this paper was conducted under the frame of the EUROFIT project.

2.1. Processing 3D body databases

Raw scan data consist of an unordered set of points with holes and noise. The application of shape analysis tools requires a preprocessing step to obtain a database of 3D body scans with the same number of points, anatomically correspondent and a clean closed surface.

The first step consists in reconstructing the surface using Poisson surface reconstruction algorithm [15] and apply surface fairing in the filled holes [16]. Once it is pre-processed, a template model is fitted like in [17]. The fact that a common template is fitted to all scans means that process ends up with a set of 3D models with homologous points, which means that there is point to point correspondence and they share the same topology.

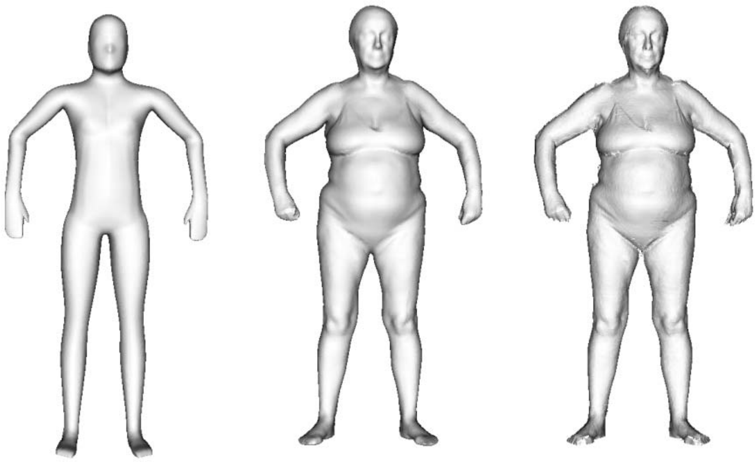

Fig. 1 Right: Template; Center: pre-processed model; Left: Original scan.

The 3D models resulting of the processing step have around 50,000 vertices (Fig 1). The dimensionality can be drastically reduced taking into account that the vertices positions are highly correlated. The application of PCA to the vertex positions of all the scans results in a quite precise representation of each model with only 100 PCA scores.

2.2. 3D reconstruction of the body from 1D measurements

There are two different goals in 3D reconstruction. One addresses the creation of a 3D model, which is as close as possible to a particular person, for whom a large set of measurements or photographs have been used. The generated 3D model in this scenario can be used for applications such as personalization or virtual dressing. The other goal is to reconstruct a model or statistical avatar that represents a certain size, which can be reconstructed using just a few key measurements (e.g. waist girth, hip girth, and leg length for representing statistical avatars of trouser sizes). Even though there are two different goals, the same approach is followed in both cases.

The process consists of two steps. In a first step a 3D approximate model is generated and in a second step it is fine-tuned.

The 3D approximate model is constructed using the technique proposed by [18]. In this work, a least-squares linear regression is calculated between the PCA scores and the measurements. One problem that may arise is the high collinearity in the measurements. This problem can be addressed using PLS-regression [19] which deals with collinear variables. Another approach we have explored is the use of a neural network that is trained with the measurements as inputs and the PCA scores as outputs. With these methods, an approximate 3D model is obtained which looks natural and has a maximum error in measurements below 3cm.

Fine-tuning step consists on an iterative process of successive minimizations of an energy function based on the squared differences of the actual measurements and the desired measurements. In each minimization, the approximate points that define the measurements are sought, and the gradients of the energy function are defined based on these points. After the minimization converges, the shape will have changed, hence the points that define the measurements will have also changed and thus the points are sought again and the energy function minimized. This process is repeated until convergence. Once the process has converged, the result is a 3D model with cero error in the optimized measurements.

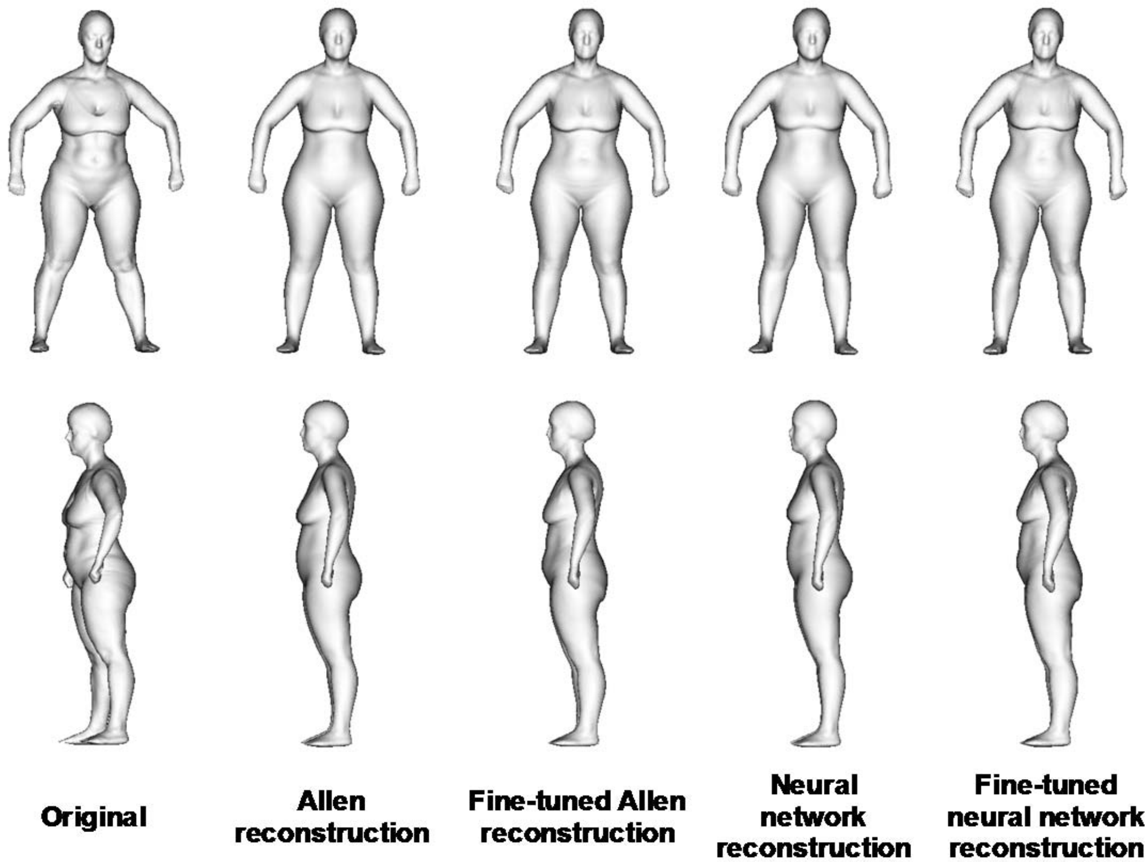

Fig 2. Reconstruction of the body from 1D measurements.

Results of 1D reconstruction tested with differ algorithms (Figure 2) are very accurate in terms of measurement optimization (table 1). However, the large number of anthropometric measures that should be introduced to obtain the 3D recreation of the body is very high for the moment. This is not operative to be done by the user at home.

Table 1. Anthropometric measurements of the 3D reconstructed model obtained with four different methods.

(mm)	**Original**	**Allen**	**Fine-tuned**	**NN**	**Fine-tuned**
Body height	1540.3	1544.1	1540.3	1546.7	1540.3
Neck height	1302.4	1306.8	1302.7	1310.8	1302.7
Waist height	879.3	882.2	879.3	887.6	879.3
Buttock height	720.6	724.9	720.6	730.8	720.6
Hip height	765.4	772.7	765.4	778.0	765.4
Crotch height	659.1	663.3	659.1	672.8	659.1
Knee height	399.8	400.6	399.8	406.1	399.8
Ankle height	75.1	76.8	75.1	76.8	75.9
Breast height	1025.0	1026.3	1024.9	1039.4	1024.9
Bust girth	944.8	935.3	944.8	931.8	944.8
Underbust	827.1	813.6	827.1	813.1	827.1
Waist girth	808.5	807.4	808.5	802.7	808.5
Hip girth	1179.6	1171.0	1179.6	1150.8	1179.6
Maximum belly	946.7	940.2	946.7	923.2	946.7
Thigh girth left	674.7	648.9	674.6	647.5	674.7
Thigh girth right	662.3	648.9	662.3	649.2	662.3
Knee girth left	414.5	403.6	414.5	394.2	414.45
Knee girth right	398.2	405.5	398.2	399.7	398.2
Calf girth left	396.7	392.5	396.7	388.9	396.7
Calf girth right	396.9	393.9	396.9	390.1	396.9

2.2. 3D reconstruction from a set of photographs

An alternative method for obtaining a 3D model from straightforward body data is to reconstruct it based on photographs. In [20], feet are reconstructed from several angles, and in [14] the body trunk is reconstructed from a front and a side photograph.

Intuitively, the idea is to depart from the mean shape and to modify PCA scores iteratively until the silhouette defined by the scores is the same than that of the photographs. In this approach, a similar idea to the one behind fine-tuning in reconstruction from 1D is used. There is a search of the points that define the silhouette so that, it is possible to define an explicit gradient with which the optimization by gradient descent method is very fast. This is done iteratively as the silhouette changes in every optimization. The final result is a 3D model with the desired silhouettes.

The feasibility of this method was proofed though an application to the foot. In this case, the acquisition process was designed to obtain the complete 3D model of the foot with only three photographs (lateral, front and medial) that can be taken by the user at home. The system uses a PCA obtained from a database of 771 feet of Spanish population from 18 to 65. The foot reconstruction is applied in this case to insole customization.

In order to evaluate the quality of this reconstruction system, both feet of 37 subjects were scanned with the INFOOT Scanner (I-Ware Laboratory, Osaka, Japan). Feet were also reconstructed from images by using the described technique. An error map from reconstruction to scan has been obtained for each foot by computing the distance between each point of the reconstruction and the scanned surface (Figure 3). The reconstruction error was defined as the average error of the points that form the 3D reconstructed foot. In this way, we have computed the average reconstruction error of the 74 feet, obtaining a value of 1.17mm.

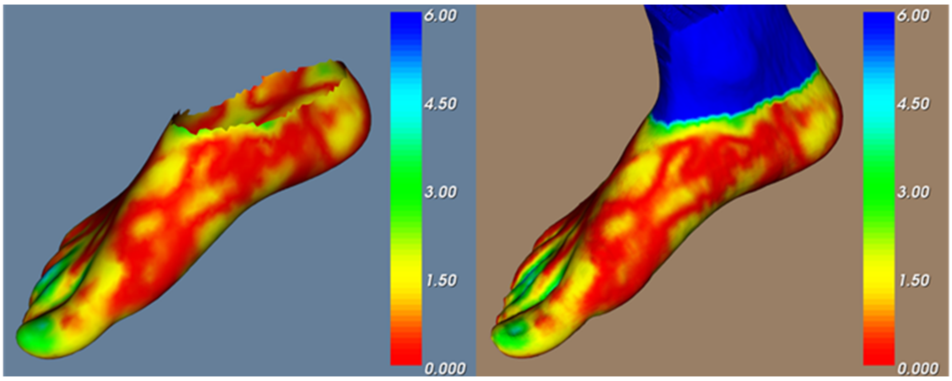

Fig.3. Error map in mm from reconstruction to scan (left) and from scan to reconstruction (right).

3D body reconstruction from a set of photographs is more difficult to apply to whole body photographs, due to the variability introduced by posture of the arms and the legs. Posture detection and correction should be developed for that case. This is very promising approach which is still a matter of research.

3. Size selection and fitting prediction from antrhopometry

The aim of this study is to analyze the viability to predict the garment fitting and size from anthropometric data of the user and explore the factors and number of body measurements that should be taken into account to obtain a high rate of prediction.

3.1. Material and methods

The experimentation performed consisted on a subjective fitting test done by 50 females from 18 to 35 and a 3D body scanning session to obtain the anthropometry. For each garment, the participants tried their respective right size, one size up and one size down. In the case of subjects fitting between two sizes, the participants tried both.

3.1.1. Description of the samples

Four garments where chosen for the experimentation: a blazer, two trousers and a skirt. The two trousers show different fitting styles and are available in a different range of sizes (Figure 4). The Trouser#2, designed with a slim fit is made with elastic material.

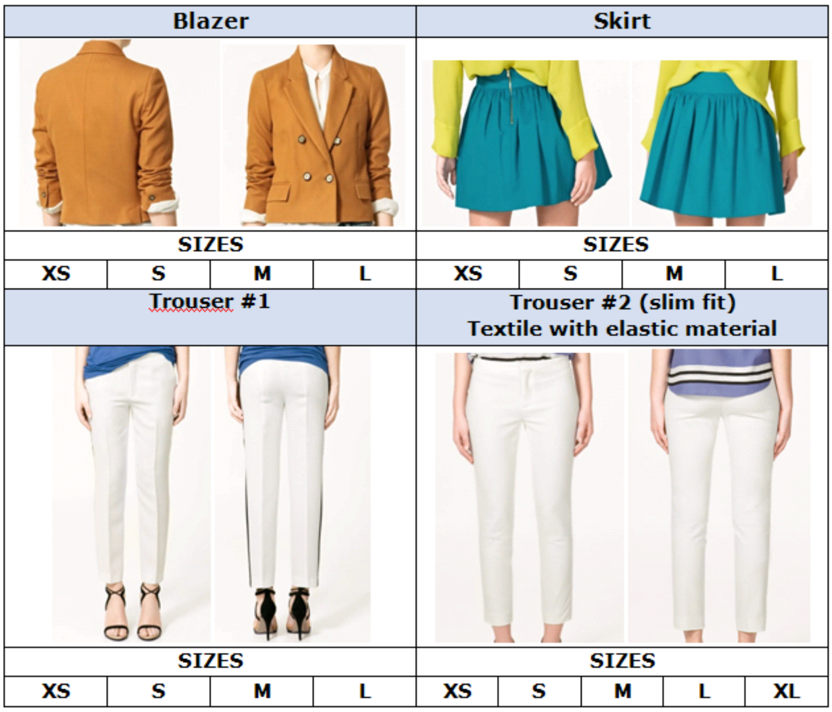

Fig.4. Garment used for the study and their respective sizes.

3.1.2. Subjective try on tests

First, the subject selected the size of the garment using the sizing table provided by the garment manufacturer. It served as a starting point for the try on test and also to validate the success rate of the current method. If the size selected was not right, the user tried new options until find her size (Figure 5). The user and an expert on garment design filled out a questioner to gather the following information:

- **Fitting perception on main body parts of the garment:** The fitting on the main body areas of each garment were rate by the user and the expert with a 5 points Likert scale. The aim was to analyze the contribution of the fitting of each body part to the final size chosen. The fitting body areas considered for each garment were:
    - **Skirt:** Waist, hip, length
    - **Blazer:** Bust, waist, hip, shoulder, back, armhole, sleeve contour, length.
    - **Trouser:** Waist, hip, thigh contour, calf contour, ankle contour, front crotch, rear crotch, trouser leg
- **Fitting preference on main body parts of the garment:** The user indicated her fitting preference for each part of the garment with a 5 points Likert scale.
- **User's size:** The final size selected by the user. Intermediate sizes could be selected in those cases in which the correct fit of the garment was estimated between two sizes.
- **Global fitting score:** the user and the expert rate the global fitting of the garment with a scale fort 1 to 10.

Fig. 5. Pictures of the try on test.

After the test of the right size, the user tested a size up and down filling out the same questionnaire obtaining a database including results of good, loose and tight fit.

3.1.3. Digital anthropometry

The 50 females were scanned on standard position using the 3D body scanner Vitus Smart. The software Anthroscan from Human Solutions was used to calculate 92 digital measures. Correspondences between each digital measurement and the fitting area of the garment were done for further analysis.

3.2. Statistical analysis

The initial statement was that garment size selection depends on the fitting of key body areas that could vary depending on the garment style. Therefore, it was developed a classification method for each garment done in two stages: 1) fitting prediction of key body parts of the garment and 2) global fitting (size prediction). The two steps approach enables the possibility to provide, apart from the best size for the user, additional information about the fitting on main body areas.

STAGE 1: The independent variables were, the size tested and the digital anthropometric measurements corresponding to each fitting area. The dependent variables tested were the fitting perception for each body part reported by the user and the expert (5 points Likert scale). The multinomial logistic regression method was applied using SPSS software to obtain the prediction models obtaining the probability to have a loose or tight fitting on the corresponding body part. The variable 'size tested' was forced on the model and the digital anthropometric measures with a discriminant contribution to predict the body part fitting where selected with an automatic stepwise process.

STAGE 2: Multinomial logistic regression was used to predict the probability of a small, big or right fitting of the garment sizes. The independent variables were the garment size and the probability to of tight, right and loose fitting of specific body parts. The variable 'garment size'' was forced on the model and the probability to of tight, right and loose fitting of specific body parts with a discriminant contribution to predict the global size fitting, where selected with an automatic stepwise process.

3.3. Results

3.3.1. STAGE 1. Fitting prediction of key body areas

The independent variables were the size tested and the main anthropometric measurements associated with the fitting of each associated with each body area. Whereas, as dependent variables were used the expert perceptions for each body part recoded to three levels: loose, right, tight.

$$\text{Probability (loose/tight fitting on body part)} = [1 + \exp(-Z)]^{-1} \quad (1)$$

$$Z= B_0+ B_1\, x_1 + B_2\, x_2 + \ldots B_n\, x_n \quad (2)$$

Where B_0, B_1, …are the coefficients obtained for the most significant fitting areas using a logistic regression, and x_1, x_2, …are the size and the significant body dimensions. As a result, it is obtained a series of equations, to predict fitting on specific body parts. In order to illustrate the results, and for extension reasons, it is showed only the results of the skirt at XS size. Table 2 summarized the resulting equations

Table. 2. Application of equations 1 and 2 for the skirt at size XS.

SKIRT		
FITTING AREA	ANTROPOMETRY	EQUATION
Waist fitting	Belly circumference (A) Hip height (B) High waist girth (C)	Z_{Tight}= -86.03+8.25-0.019*A+0.488*B+0.576*C Z_{Loose}= 70.21-10.78-0.422*A-0.214*B-0.154*C
Hip fitting	High hip girth (A) Hip height (B)	Z_{Tight}= -51.07+4.22+0.293*A+0.271*B Z_{Loose}= 56.74-9.04-0.499*A-0.167*B
Length fitting	Knee height (A) Buttock girth (B)	Z_{Tight} = -40.25+1.63-0.453*A+0.188*B Z_{Loose} = 41.31+16.22-0.730*A-0.313*B

3.3.2. STAGE 2. Size prediction

The independent variables were the garment size and the fitting probabilities of body parts obtained from first step. Whereas, the dependent variable was the size selection recoded to: tight (-1), right (0), loose (1).

The logistic equation was used to identify the most influent body part fittings when choosing a size for each garment and the coefficients associated (B_0, B_1, …). Table 3 shows the equations resulting for the skirt to obtain the probability for each size to be tight, loose or right.

Table. 3. Equations to predict the fitting of the XS size of the four garments..

GARMENT	SIGNIFICATIVE MISFITTINGS	EQUATION
SKIRT	Short length (A) Loose waist (B)	$Z_{Tight}=1.38-3.00+4.95*A-10.55*B$ $Z_{Loose}=0.97-6.47-5.06*A+5.76*B$
BLAZER	Tight armhole (A) Right sleeve contour (B) Loose sleeve contour (C) Right sleeve length (D)	$Z_{Tight}=-1.05+2.56+3.34*A-2.52*B-3.63*C-2.73*D$ $Z_{Loose}=-4.25-4.45-3.76*A+4.83*B+7.85*C+2.85*C$
TROUSER #1	Loose waist (A) Loose thigh (B) Tight calf (C) Loose rear crotch(D) Long length (E)	$Z_{Tight}=3.81-3.13*A-36.73*B+7.60*C-22.56*D-0.13*E$ $Z_{Loose}=-11.73+7.69*A+8.45*B-19.82*C+3.01*D+3.23*E$
TROUSER #2	Loose waist (A) Tight thigh (B) Right thigh (C) Tight calf (D)	$Z_{Tight}=-2.98+0.06-1.43*A+3.48*B-0.22*C+2.06*D$ $Z_{Loose}=-1.31+4.10+6.11*A-3.26*B-8.80*C-6.16*D$

3.3.3. Validation of the method

Figure 6 plots the rate of success of the three methods (usual size, size table and statistical predictor) compared with user choice during the try on test. The results show that customers have a real difficulty nowadays choosing the most suitable size (up to a 95% of error). The proposed statistical predictor improves the possibility of a good selection (86-93%).

The statistical predictor also reduces the uncertainty during the apparel purchase since it provides not only the best size but the different fitting level in each body area as well.

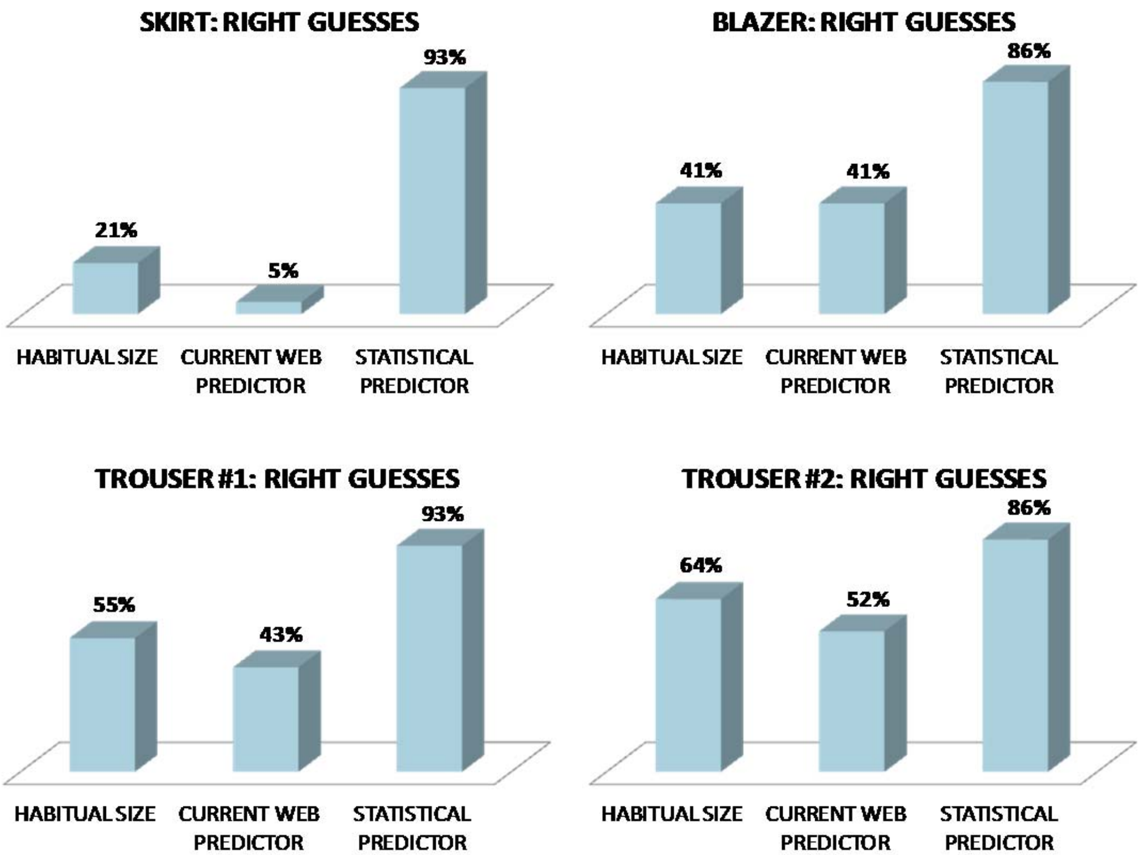

Fig. 6. Rate of success of the three methods (usual size, size table and statistical predictor) compared with user choice during the try on test.

4. Conclusions

The present paper analyzes the size selection process of garment integrating new emerging technology of body shape registration and providing knowledge about the relationship between the anthropometric measures of the user body and the garment size.

The acquisition of body anthropometry should be accurate and reliable. A widespread method should also enable an easy integration with the shopping experience. From this perspective, it is presented the viability of a novel data driven approach based on the 3D reconstruction of 3D body shapes from a small number of photographs using electronic consumer goods. The proposed method was used with confident results for the foot reconstruction using three pictures. However, for the whole body reconstruction required in the apparel market, it is necessary to solve the correction of the body posture.

The limitation of the 3D reconstruction process proposed is the need of 3D databases. Since the 3D anthropometric studies done in the last decade cover almost worldwide, the ownership conditions often share between several private sponsors and public administrations make difficult the possibility to exploit the data. This situation prevents to take profit of the data at industrial level. It is necessary to progress on exploitation models that could overcome this situation.

The second part of the paper, dedicated to the study of the garment fitting, gives several clues about the difficulties to model the selection of the garment size with body anthropometry. In contrast with the sizing tables that use only one or maximum two primary dimensions to select the size, the prediction of the garment fitting and the size selection is multivariate and depends on several body dimensions. The tight and loose fit of a critical area does not act in the same way in the size section. Depending on the garment style, the tight fit could be more restricting. The results for the two types of trousers show that the garment style modifies the contribution of the user anthropometry to select the size. This poses a problem when generating a global size selection model for each garment.

The successful rate of the size selection provided by the statistical models proposed compared with the usual size declared by the user and the results of the current process based on a sizing table shows a significant improvement. However, the investment required to generate this models prevent its industrial implementation.

Nevertheless, these results contribute to the understanding of factors driven the size selection. This knowledge provides a starting point to define a new multidimensional approach to model size selection. In that case, it is required a more systematic process to develop new garments: to use an stable anthropometric reference to develop the basic size and to follow regular scaling methods. The purpose is to track the process from the design process, where the fitting of the garment is validated for the basic size, to the mass production of the whole range of sizes.

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