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Publisher's version / Version de l'éditeur:

IEEE Transactions on Instrumentation and Measurement, 56, 5, 2007-10

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October 2007

* published in IEEE Transactions on Instrumentation and Measurement. Volume 56, Issue 5. pp. 1924-1929. October 2007. NRC 48821.

Canada

Adjustment of Virtual Mannequins through Anthropometric Measurements, Cluster Analysis and Content-based Retrieval of 3-D Body Scans

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Abstract* – Computer generated models of the human body generally do not adequately model the complex human morphology. These models therefore do not reflect the anthropometric realities and are not specific enough for commercial use. This paper presents an approach to adjust virtual models through the use of body measurements as obtained from an anthropometric data set. In this approach, the measurements are used to group three-dimensional body scans, obtained using precise opto-electronic measurement devices, into clusters. The virtual mannequins are then adjusted by using the measurements of nearest cluster member. In this way, realistic, accurate virtual mannequins are created.

I. INTRODUCTION

The adjustment of virtual models to fit real world measurements provides an important challenge to the research community. In particular, computer generated models of the human body usually do not adequately model the complex human morphology. The modelling of a large number of detailed and interrelated characteristics, such as knee height, head circumference, hip breadth and foot length, to name but a few, are difficult. This may lead to virtual models which do not reflect anthropometric realities and are therefore not specific enough for commercial use.

The concept of a virtual mannequin has many applications in e.g. e-commerce and design. For example, consider an e-commerce website used to sell clothes to consumers. To aid the consumer to purchase clothes with an accurate fit, a virtual mannequin is generated, based on the parameters as entered by the consumer. It is important that the resultant model is not only aesthetically pleasing, but fits the clothes properly. That is, it should be ensured that the virtual mannequins are anthropometrically correct. Otherwise, the consumer may either take his business elsewhere, or the number of goods being returned may be unacceptably high.

Anthropometry is the science of measurements used in order to establish the physical geometry, mass property and strength capabilities of the human body [1]. Through the use of manual measurements by domain experts, combined with precise opto-electronic measurement devices, an accurate model of the human body and its measurements can be obtained. Such precise data provides us with an opportunity to engineer realistic virtual models of the human body.

This paper describes an approach to adjust virtual models through the use of cluster analysis against an accurate database containing body measurements as well as 3-D scans of human subjects. The human bodies are grouped into clusters that are similar to one another and are dissimilar to the subjects in other clusters. When using the measurement of the so-called cluster Centroid to adjust these virtual mannequins, they can be made more realistic. This *a priori* knowledge about the measurements of typical human bodies is used to produce highly accurate virtual mannequins.

This paper is organized as follows. Section 2 provides an overview of the CAESAR™ database used in this research and discusses the global indexing approach used to describe the 3-D body scans. In Section 3, the method used to adjust the virtual mannequins, in order to create realistic proportioned bodies, is discussed. Section 4 concludes the paper.

II. CAESAR™ DATABASE

Anthropometry is the study of human body measurements (height, weight, size, proportions, etc.) and its biomechanical characteristics. The name derives from the Greek *anthropos*, meaning human, and *metrikos*, meaning “pertaining to measuring”. According to Roedig [1], anthropometric measurements are critical for the analysis and development of engineering design requirements, in order to help evaluate e.g. distances to reach controls or to clearly separate the body from environmental hazards. The science of human body measurements has wide application when specifying the engineering requirements for lighting, keyboards, flight simulators and physical modelling, amongst many others.

Anthropometric data thus refer to a collection of physical dimensions of a human body. The aim of anthropometry is therefore to characterize the human body by a set of measurements. The CAESAR™ Project is an international anthropometric survey that was carried out in the United States, Italy, the Netherlands and Canada. This survey involved thousands of individuals in each country.

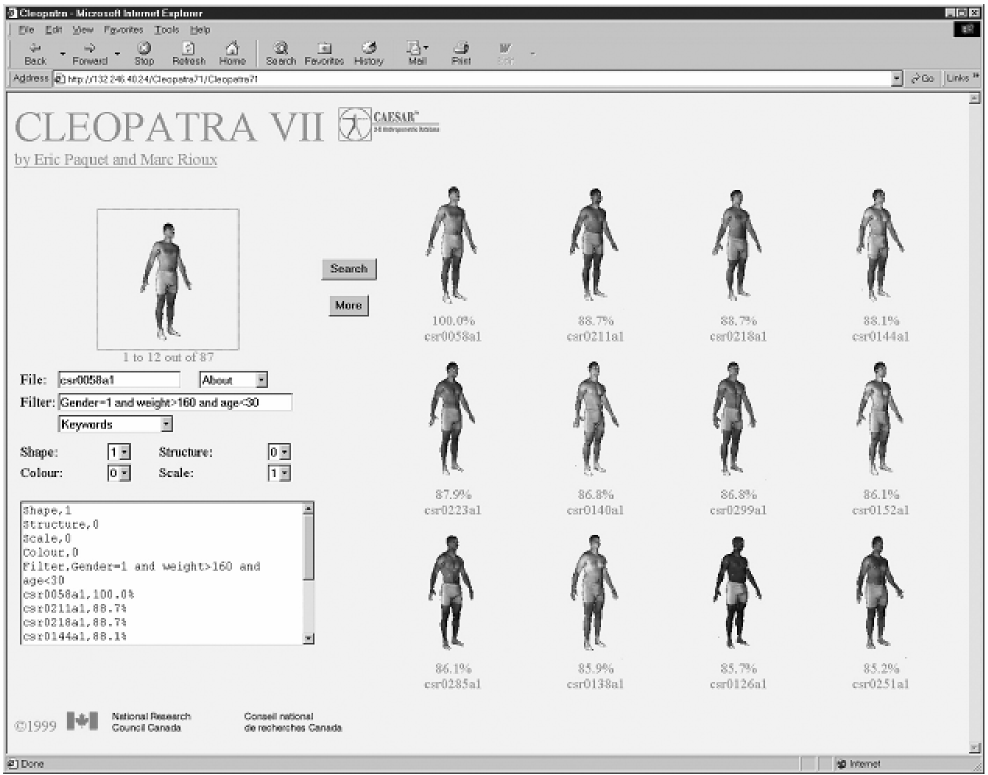

Fig. 1. An example of 3-D human body scans as contained in the CAESAR™ database.

For each individual, a series of accurate anthropometric measurements was performed and questions of demographic nature were recorded such as family income, car brand, perception of height, etc. What makes the originality of this survey is that each person was scanned in three dimensions using a full body scanner. Different types of technologies were used but they are all built around the same principles: a few laser scanners move along a rigid frame and capture a full body scan in a few seconds. Each subject was scanned in three different postures [7, 8]. The CAESAR™ Project is sponsored by the US Air Force and involves about 40 contributing multinational companies mainly from the transportation and the apparel industry. The main aim of this project is to provide better fitting commercial products, including cars and clothing.

In particular, for each of the individuals scanned, the CAESAR™ anthropometric database contains forty-nine body measurements, including details such as the arm length (spine to wrist, shoulder to wrist and elbow to wrist), the shoulder breadth, the acromial height (sitting), the triceps skinfold, the waist circumference, the ankle circumference and the eye height. This database thus represents a detailed and accurately measured subset of the typical human morphology, together with a 3-D body scan which maps these measurements.

Figure 1 shows some of the body scans as retrieved via the Cleopatra interface, which is used to query and retrieve data from the CAESAR™ database.

The 3-D body scans are described using a global shape-based descriptor, which is an abstract and compact representation of the three-dimensional shape of the corresponding body [9, 10]. The descriptor is computed as follow. Firstly, a scale, translation, rotation and reflection invariant reference frame is calculated from the principal axis of the tensor of inertia of the human body. The principal axes correspond to the eigenvectors of the tensor of inertia. It can be shown that the normalized principal axes are translation, scale and rotation invariant. By applying a suitable transformation, reflection invariance can be obtained. The axes of the reference frame are identified or labelled by their corresponding eigen values.

The three-dimensional shape descriptor is based on the concept of a cord. A cord is defined as a vector that goes from the centre of mass of the human body to the centre of mass of a given triangle modelling its surface. It is thus assumed that a triangular mesh represents the surface of the human body. The distribution of the cords is represented by three histograms. The first histogram represents the angular distribution between the cords and the eigenvector with the highest eigen value. The second histogram represents the angular distribution between the cords and the eigenvector with the second highest value. The distribution of the radii is represented by a third histogram. This histogram is scale-dependent, but it can be made scale-independent by normalizing the scale based either on the maximum radius or on the average radius. Note that all descriptors must have an identical normalization in order to be comparable.

III. ADJUSTING VIRTUAL MANNEQUINS

This section describes the system used to adjust the virtual mannequins, from an anthropometric point of view, through the use of cluster analysis against the CAESAR™ body measurement data.

The aim of this research was to create realistic virtual mannequins to be used by the consumers of an e-commerce website. Here, the virtual mannequins may be used by the consumer in order to see the fit thereof against his/her body. It is therefore important that the mannequin is morphologically accurate, in order to ensure that the consumer has a realistic view of how the clothes will fit his/her body type. Otherwise, the number of dissatisfied consumers (and clothing returns) may be unacceptably high.

Fig. 2. An example of a virtual mannequin [11]

We completed this research using the National Research Council of Canada (NRC) Cleopatra multimedia data mining system to access the 3-D body scans and to verify the quality of the end results. The WEKA data mining system, a Java-based knowledge learning and analysis environment developed at the University of Waikato in New Zealand, was used to cluster the data [12]. We present the results of our experimentation when adjusting male virtual mannequins here.

Consider a collection of aesthetically pleasing computer-generated virtual mannequins, similar to the one depicted in Figure 2. These virtual mannequins are based on a limited number of user-specific criteria, such as waist circumference, chest and weight [13]. Table I shows the 'ideal" male body measurements and clothing sizes used to produce clothing to fit the male population. However, inspection of the typical body measurements of the male population, as contained in the CAESAR™ database, shows that the population does not fit this ideal. Subsequently, the mannequin adjustment system proceeds to fit these virtual mannequins against the CAESAR™ database, as follows.

Table I. Ideal body measures for standard clothing sizes [13].

	Small		Medium		Large		X-Large		XX-Large	
	34	36	38	40	42	44	46	48	50	52
Chest	87	92	97	102	107	112	117	122	127	132
Waist	71	76	81	87	92	97	107	112	117	122
Hip	89	94	99	104	109	114	119	124	130	135
Neck	35.5	37	38	39.5	40.5	42	43	44.5	46	47
Sleeve	81	81	84	84	87	87	89	89	91	91
Stature	178	178	178	178	178	178	178	1.78	1.78	1.78

Table II. A subset of the body measurements contained in the CAESAR™ database.

Measurement	Measurement
Acromial Height Sitting	Spine to Shoulder Length
Ankle Circumference	Spine to Elbow Length
Arm Length: Spine to Wrist	Arm Length: Shoulder to Wrist
Arm Length: Shoulder to Elbow	Arm Circumference
Bust Chest Circumference	Buttock Knee Length
Crotch Height	Eye Height Sitting
Face Length	Foot Length
Hand Length	Shoulder Breadth
Sitting Height	Vertical Trunk Circumference
Triceps Skinfold	Head Circumference
Knee Height Sitting	Thumb Tip Reach
Head Breadth	Hand Circumference

Firstly, the 3-D body scans were grouped into a user-specified number of clusters, formed through the clustering of the anthropometric data. For this research, initially the number of available clothes sizes, i.e. *five* sizes, to denote small, medium, large, extra-large and extra-extra-large, was used as parameter.

The data set consisted of the 3-D body scan of the male subject facing the scanner, together with 49 anthropometric measures. A total of 418 male subjects were used. Table II shows a subset of the body measurements which were recorded. The table shows that numerous details, such as the length of the face, the knee height sitting and the length between the buttocks and knees, were measures. Initially, a number of clustering algorithms was applied to the data. These included the EM algorithm, the CobWeb method, the k-means technique and the Farthest First approach [12]. Also, an algorithm using a variation of the density-based clustering algorithm with simple k-means component classifiers was employed. The clustering algorithms input the body measurements and the number of clusters to be formed. The methods proceeded to construct the clusters and outputs *five* groupings, based on these measurements. Table III shows the cluster membership when applying the different cluster analysis methods to the data. Note that the CobWeb algorithm failed to converge.

Table III. Cluster membership information

	Small	Medium	Large	X-Large	XX-Large
CobWeb	-	-	-	-	-
Farthest First	13 (3%)	252 (61%)	92 (22%)	55 (13%)	2 (0%)
EM	113 (27%)	122 (29%)	81 (20%)	70 (17%)	28 (7 %)
k-means	62 (15%)	131 (31%)	131 (31%)	52 (13%)	38 (9%)
Density-based	85 (21%)	138 (33%)	78 (19%)	94 (23%)	19 (5%)

By inspection, through using the WEKA and the Cleopatra data mining systems, the k-means classifier algorithm was found to produce the best clusters, when evaluated in terms of cluster membership. That is, the k-means algorithm produced the best Centroids both in terms of the body measurements and as verified by our inspection of the corresponding 3-D scans. For example, for the large and extra-large clusters, the density-based method produced two overlapping clusters, where the Centroids had similar waist circumferences (95.5 versus 97.2 cm) and weights (212.6 versus 214.1 pounds). The EM algorithm produces clusters which were biased towards the larger individuals. Similarly, the Farthest First algorithm produced skew clusters and failed to distinguish between small, medium and large individuals.

The resultant clusters, as obtained by the k-means algorithm, are shown in Figure 3. The k-means algorithm is a Centroid-based partitioning technique, in which each cluster is represented by the mean value of the objects in the cluster and the Centroid is viewed as the cluster's centre of gravity. This technique is highly suitable for discovering similar sized clusters with convex shapes, on numeric attributes. Also, it works well with domains with little noise or outliers. Recall that the body measurements were recorded by domain experts, making the level of noise and occurrence of outliers rare.

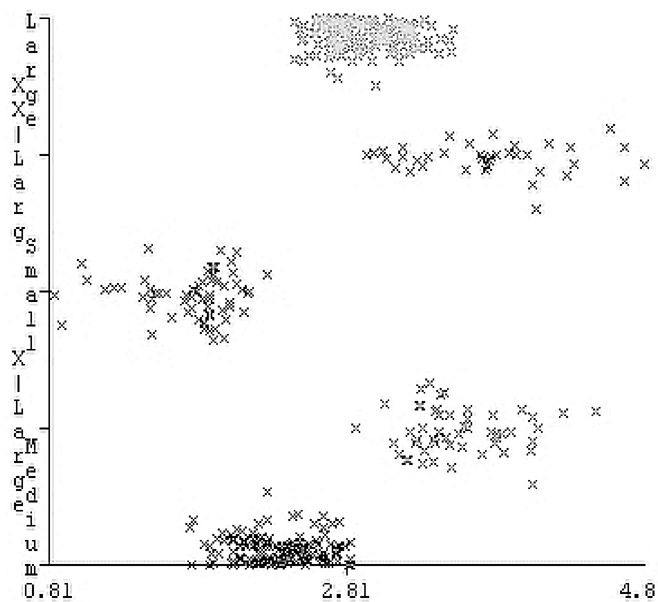

Fig.3. Visualization of resultant clusters

Table IV shows a subset of the body measurements of the Centroids of the five clusters of the male population. Shown are the means (in cm) and standard deviations of each of the clusters and the number of cluster members.

The bodies of the human subjects who correspond to these measurements are shown in Figure 4. It is interesting to note that, when e.g. distinguishing between large and extra-large subjects within the male population, the chest and hip circumferences do not differ substantially. Rather, the waist circumference and stature is of importance here. This reality is not reflected in the "ideal" clothing sizes, as shown in table II, and is thus an important factor to consider when adjusting the virtual mannequins.

Table IV. Body measurements of cluster Centroids as contained in the CAESAR™ database.

	Small	Medium	Large	X-Large	XX-Large
Chest	94.9 (5.9)	99.4 (6.8)	106.1 (6.19)	106.9 (6.6)	125.7 (10.9)
Waist	82.0 (6.8)	86.8 (6.8)	92.3 (7.5)	107.8 (7.0)	116.6 (16.0)
Hip	96.70 (4.80)	101.14 (4.93)	106.48 (5.42)	108.39 (4.90)	123.15 (14.33)
Neck	44.6 (1.9)	46.0 (2.0)	48.0 (2.19)	48.7 (2.0)	52.7 (3.04)
Arm Length	59.5 (2.03)	62.4 (1.79)	65.08 (1.71)	68.7 (1.96)	65.56 (3.02)
Stature	167.0 (5.9)	174.7 (3.5)	180.6 (3.6)	190.0 (5.0)	181.9 (4.6)
Sitting Height	56.82 (2.47)	59.47 (2.45)	61.35 (2.26)	63.78 (2.84)	64.65 (2.41)
Hip Breadth Sitting	35.67 (3.13)	37.22 (2.09)	39.04 (2.3)	40.20 (2.23)	45.10 (4.55)
Shoulder Breadth	44.65 (1.90)	45.96 (2.03)	48.00 (2.19)	48.69 (2.00)	52.66 (3.04)
Waist Front Length	41.95 (3.36)	44.70 (3.46)	46.86 (3.94)	48.45 (3.41)	54.33 (4.15)
Weight (lbs)	151.17 (15.77)	172.19 (17.70)	198.16 (18.61)	212.85 (20.04)	274.99 (35.9)
Number of Members	62 (15%)	131 (31%)	131 (31%)	52 (13%)	38 (9%)

Next, the 3-D body scan clusters were used to adjust the virtual mannequins. The virtual mannequins that fit within a cluster were retained, while outliers were discarded. The 3-D body scan of the human subject which was *closest* to the virtual mannequin was retrieved and subsequently used to adjust the virtual mannequin. For example, the breadth of the hips and the length of the legs of the virtual mannequin may be updated to more realistically reflect the typical human body.

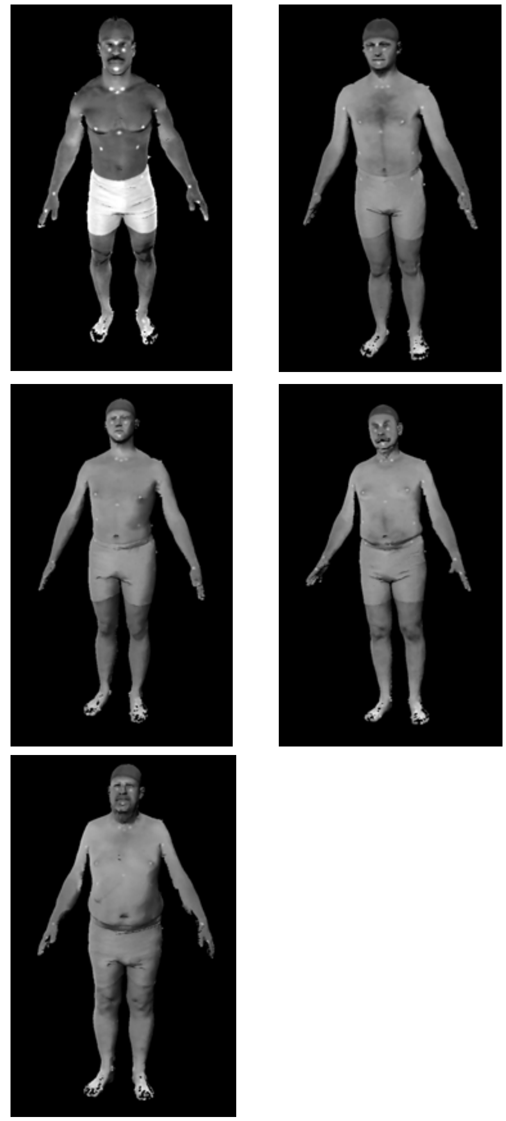

Fig. 4. The 3-D Body Scans of the Centroids of the five clusters, from size Small (top left) to Extra-extra-large (bottom right).

Figure 5 shows a resultant virtual mannequin for the large clothing size. The original mannequin, with measurements chest, waist, hip and stature of 112, 97, 114 and 178 (in cm), respectively, was modified by obtaining the nearest human body measurements. In this figure, the chest, waist, hip and stature measurements of the resultant mannequin are set to 112.4, 95.2, 114.0 and 185.4 (in cm), respectively. That is, the chest and waist measurements were slightly reduced, whilst the stature was increased. The number of virtual mannequins generated for each cluster is user-specified, but should be at least one.

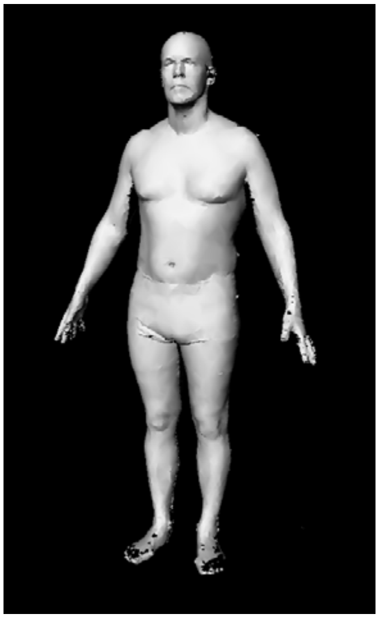

Fig. 5. An example of a realistic virtual mannequin corresponding to the large clothing size.

The final set of virtual mannequins can now be placed in a database to be used when the e-commerce site is visited by consumers. When a consumer enters his data, the virtual mannequin that is closest to his measurements is selected and displayed. The consumer then proceeds to use this virtual mannequin to try on clothes to see the fit thereof against a realistic, aesthetically pleasing representation of his own body.

IV. CONCLUSION

This paper described a novel approach which used the detailed body measurements and 3-D body scans of human subjects to adjust virtual, computer-generated models of the human body. Through the use of cluster analysis and the matching of the initial virtual models with 3-D body scans, the virtual mannequins were adjusted to realistically represent the typical human body. In summary, the advantage of using a cluster analysis approach is that we can detect the natural groups, in the form of clusters, as based on accurate body measurements. Subsequently, we are able to use these grouping to produce computer-generated models that correspond to the 3-D scan of an existing human subject and are thus anthropometrically correct.

For many applications, such as marketing, it is important to note the interrelationship between demographic and anthropometric attributes when considering e.g. the level of family income. Current and future research includes the investigation of the demographic profiles of the members of the individual clusters in order to obtain new insights into the male population [14]. The results of this research has commercial application, e.g. to aid designer when designing a luxury car or clothing for low income males within a certain age range, amongst others. Tailors have long recognized that it is very difficult to design clothes based on flat patterns that fit comfortably on the complex, 3-D curves of the human body [1]. Another important issue that therefore needs to be further investigated is ensuring the correct fit of the clothes against the resultant mannequins, as discussed in [15].

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