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Anthropometric Calibration of Virtual Mannequins Through Cluster Analysis and Content-based Retrieval of 3-D Body Scans *

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Anthropometric Calibration of Virtual Mannequins through 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 calibrate 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 into clusters. The virtual mannequins are then calibrated by using the measurements of nearest cluster member. In this way, highly realistic, accurate virtual mannequins are created.

I. INTRODUCTION

The calibration 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 unacceptability high. The use of cluster analysis to calibrate the virtual mannequin through the use of an existing database of accurately scanned and measured human bodies, provides a novel approach to address this problem.

Cluster analysis is a data mining technique that deals with the extraction of the implicit knowledge, data relationships or other patterns not explicitly stored in databases, by grouping related records together [1, 2]. A cluster is a collection of objects that are similar to one another and are dissimilar to the objects in other clusters. The goal of clustering is to find inter-cluster similarity and intra-cluster dissimilarity, through the discovery of a hidden pattern that gives meaningful groups (clusters) of objects. A number of clustering techniques exist, varying in the amount of a-priori knowledge required, the scalability, the number of clusters which can be found and the data types supported [1-6].

This paper describes an approach to calibrate virtual models through the use of cluster analysis against a highly accurate database containing body measurements as well as 3-D scans of human subjects. This a priori knowledge about the measurements of typical human bodies is used to produce highly accurate, realistic virtual mannequins. 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 calibrate the virtual mannequins is discussed. Section 4 concludes the paper.

II. CAESAR™ DATABASE

The CAESAR™ Project is an international anthropometric survey that was carried on in the United States, Italy, Netherlands and Canada. This survey involved thousands of individuals in each country. For each individual, a series of highly 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.
Anthropometry is the study of human body measurements (height, weight, size, proportions, etc.) and its biomechanical characteristics. Anthropometric data 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. 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 follows. 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 Eigen vectors 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 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 Eigen vector with the highest Eigen value. The second histogram represents the angular distribution between the cords and the Eigen vector 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. CALIBRATING VIRTUAL MANNEQUINS

This section describes the system used to calibrate 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 calibrate 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.

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 calibrating 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 calibration system proceeds to calibrate these virtual mannequins against the CAESAR™ database, as follows.

![Fig. 2. An example of a virtual mannequin [11]](image)

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.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acromial Height Sitting</td>
<td>Spine to Shoulder Length</td>
</tr>
<tr>
<td>Ankle Circumference</td>
<td>Spine to Elbow Length</td>
</tr>
<tr>
<td>Arm Length: Spine to Wrist</td>
<td>Arm Length: Shoulder to Wrist</td>
</tr>
<tr>
<td>Arm Length: Shoulder to Elbow</td>
<td>Arm Circumference</td>
</tr>
<tr>
<td>Bust Chest Circumference</td>
<td>Buttock Knee Length</td>
</tr>
<tr>
<td>Crotch Height</td>
<td>Eye Height Sitting</td>
</tr>
<tr>
<td>Face Length</td>
<td>Foot Length</td>
</tr>
<tr>
<td>Hand Length</td>
<td>Shoulder Breadth</td>
</tr>
<tr>
<td>Sitting Height</td>
<td>Vertical Trunk Circumference</td>
</tr>
<tr>
<td>Triceps Skinfold</td>
<td>Head Circumference</td>
</tr>
<tr>
<td>Knee Height Sitting</td>
<td>Thumb Tip Reach</td>
</tr>
<tr>
<td>Head Breadth</td>
<td>Hand Circumference</td>
</tr>
</tbody>
</table>
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 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. By inspection, however, the simple k-means classifier algorithm was found to produce the best clusters, when evaluated in terms of cluster membership. In this approach, the number of initial clusters and the initial centroid of each cluster are randomly selected. Next, descriptors are assigned to their closest cluster centre and the new mean value is calculated. This iterative process continues until the data are assigned to each cluster in consecutive rounds. At this point, the cluster centres are thus stabilized and finalized.

Fig. 3. The 3-D Body Scans of the Centroids of the five clusters, from size Small (top left) to Extra-extra-large (bottom right).
The clustering algorithm input the body measurements and the number of clusters five (5) to be formed. It proceeded to construct the clusters and outputs five groupings, based on these measurements. Table III shows a subset of the body measures 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 3. 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 and is thus an important factor to consider when calibrating the virtual mannequins.

Next, the 3-D body scan clusters are used to calibrate the virtual mannequins. The virtual mannequins that fit within a cluster are retained, while outliers were discarded. The 3-D body scan of the human subject which is closest to the virtual mannequin is retrieved and was subsequently used to calibrate 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.

Figure 4 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 calibrated 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.

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 calibrate virtual, computer-generated models of the human body. Through the use of clustering and the matching of the initial virtual models with 3-D body scans, the virtual mannequins were calibrated 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. Another important issue that needs to be further investigated is ensuring the correct fit of the clothes against the resultant mannequins, as discussed in [15].

REFERENCES


