Virtual test persons based on diverse anthropometric data for ergonomics simulations and analysis

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This paper describes a study where diverse anthropometric data is included in the process of generating data for a group of virtual test persons. Data on body size, strength and ROM were either collected on an individual level or predicted and synthesized and then used in cluster analyses to generate six unique virtual test persons. Results show that the method is able to generate detailed virtual test persons which enables more realistic and accurate simulations, as strength and ROM data is included into the motion prediction algorithms used to generate motions.

Keywords: Virtual, test persons, diversity, Digital Human Modelling, strength, range of motion, cluster analysis

1. Introduction

In a design process, good ergonomics is achieved when the capabilities of humans match the demands made by the product, workplace or system. Digital human modelling (DHM) tools enable simulations and analyses of ergonomics in virtual environments, particularly at early design stages when the product and workstations often only exist in a virtual format (Chaffin et al., 2001; Duffy, 2009; Hanson et al., 2012). Restrictions in the physical interaction between humans and systems can often be connected to body dimensions of the users. Several methods have been developed for the consideration of body size related anthropometric diversity in design (Meindl et al., 1993; Speyer, 1996; Bittner, 2000; Dainoff et al., 2004; Brolin et al., 2012). The most frequent referenced and used method is the boundary case method in where cases are defined as points located towards the edges of a population distribution (Dainoff et al., 2004).

However, the human-machine interaction is not only affected by the size and proportions of a user but also other physical user characteristics, e.g. muscle strength and joint range of motion (ROM) (Frey Law et al., 2009). Due to the low correlation between and in-between different groups of variables, especially for ROM variables, the boundary case method has shown to have limited use when applied on data of body size, strength and ROM (Brolin et al., 2014). Instead, cluster analysis have shown to be an appropriate alternative as it enables the generation of distributed test cases with different body size, strength and ROM, and indeed also other capability measures when data is available (Brolin et al., 2016). Cluster analysis is done by grouping a set of objects in subsets called clusters in such a way that objects in the same cluster are similar to each other and objects in different clusters are as dissimilar as possible (Kaufman and Rousseeuw, 2009). The data that comes out of a cluster analysis of anthropometric data could be used as the basis to construct more detailed user characters or personas, often used in product design, software development and human computer interaction studies (HCI). Personas is a user representation approach that supports descriptions and communication about users' abilities and requirements (Pruitt and Grudin, 2003). Each persona is given a name and is described with different personal characteristics and background details and serves as representations of real users throughout the design process (Cooper, 1999). Adopting the concept of personas in the context of DHM tools can result in computer manikins becoming DHM Personas, as exemplified in (Högberg et al., 2009). This paper describes a study where diversity in body size, strength and ROM, is included in the process of generating data for a group of virtual test persons for the digital human modelling tool IPS IMMA, using cluster analysis.

2. Methodology

The procedure for generating virtual test persons (Figure 1) for the IPS IMMA tool starts with obtaining body size, strength and ROM data. Cluster analysis needs to be performed on raw data on an individual level and to achieve this, prediction and synthesizing of missing population data needs to be done (Brolin et al., 2016). Data on ROM, age, sex, stature and body weight were extracted for adult individuals from a U.S. database provided by CDC (Centers for Disease Control and Prevention) (Soucie et al., 2011). This data, on an individual level for 266 women and 210 men, formed a basis to predict and synthesize additional strength and body size data.

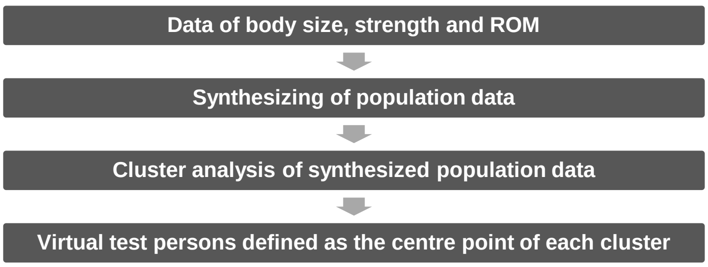

Figure 1 Procedure for generating virtual test persons by synthesizing and clustering of data

2.1. Synthesizing of population data

Strength data was predicted using previously published regression equations (Andrews et al., 1996) with gender, age and weight as predictive variables. The variance of the predicted strength data was also estimated by adding a stochastic component to each predicted measurement. These stochastic components was based on the partial correlation coefficients and the partial standard deviation (Brolin et al., 2017). In this case the partial correlation coefficients were unknown but estimated to 0.415 and 0.425 for female and male data respectively. This was done iteratively to give an average value, for the final correlation coefficients between different strength measurements, similar to the average values of the correlation coefficients presented in Brolin et al. (2014), which originates from Shklar and Dvir (1995) and Mathiowetz et al. (1985). The partial standard deviation which is the same as the root mean square error (RMSE) could be calculated for the given regression equations as

$$RMSE = \sqrt{(1 - R^2) \times \sigma_c^2},$$

where the coefficient of determination, R^2 is given for each regression equation (Andrews et al., 1996) and σ_c is the combined calculated (Dunlap, 1937) standard deviation values for all three age groups and both sexes. The regression equations presented in Andrews et al. (1996) are limited to an older population (50-79 years). Therefore the estimated strength for each individual younger than 50 years was adjusted using the estimated strength of a 50 year old person and the average of the regression coefficients provided by Lindle et al. (1997). This gave an additional equation for each sex (female = f and male = m) as

$$Strength_f(age) = Strength_f(50) \times (0.7804 + 0.0161 \times age - 0.0002 \times age^2),$$
$$Strength_m(age) = Strength_m(50) \times (1.0114 + 0.007 \times age - 0.0001 \times age^2).$$

Additional body size data was predicted using individual based descriptive statistics from Swedish anthropometric data (Hanson et al., 2009) using a synthesizing procedure presented in Brolin et al. (2017). The prediction of additional body size data used body weight and stature as predictive variables. As in Brolin et al. (2017), to better consider positively skewed distributions such as width and circumference measurements a method presented and included in the software PeopleSize (2008) is used, in this study together with body weight data from National Health and Nutrition Examination Survey (NHANES) (U.S. Centers for Disease Control and Prevention, 2008).

2.2. Cluster analysis of synthesized data

The process of predicting, estimating and synthesizing data gave a dataset of 46 variables on an individual level, necessary for generating digital manikins in IPS IMMA. The synthesized data was used in cluster analysis where the clustering algorithm was set to give six unique distributed cases and each case was given by taking the average value of all individuals belonging to a specific cluster. The sex of each case was determined as either female or male and the age of each case was rounded to nearest integer. To solve the problem of grouping objects into clusters a number of different types of algorithms exist such as hierarchical based, optimization based and density function based (Everitt et al., 2011). In this study hierarchical clustering was used as it was found, through initial analysis, to be the most appropriate algorithm as it gave the diverse distributed cases and spanned a big range of percentile values.

2.3. Visualisation and simulation

The resulting virtual test persons were visualised using the software MakeHuman (MakeHuman, 2017) and its functionality to generate mesh models through the definition of a number of variables. These variables could be defined using the data from the cluster analysis. In future versions of IPS IMMA, mesh models generated in MakeHuman, or similar software, will be possible to directly import into the IPS IMMA software.

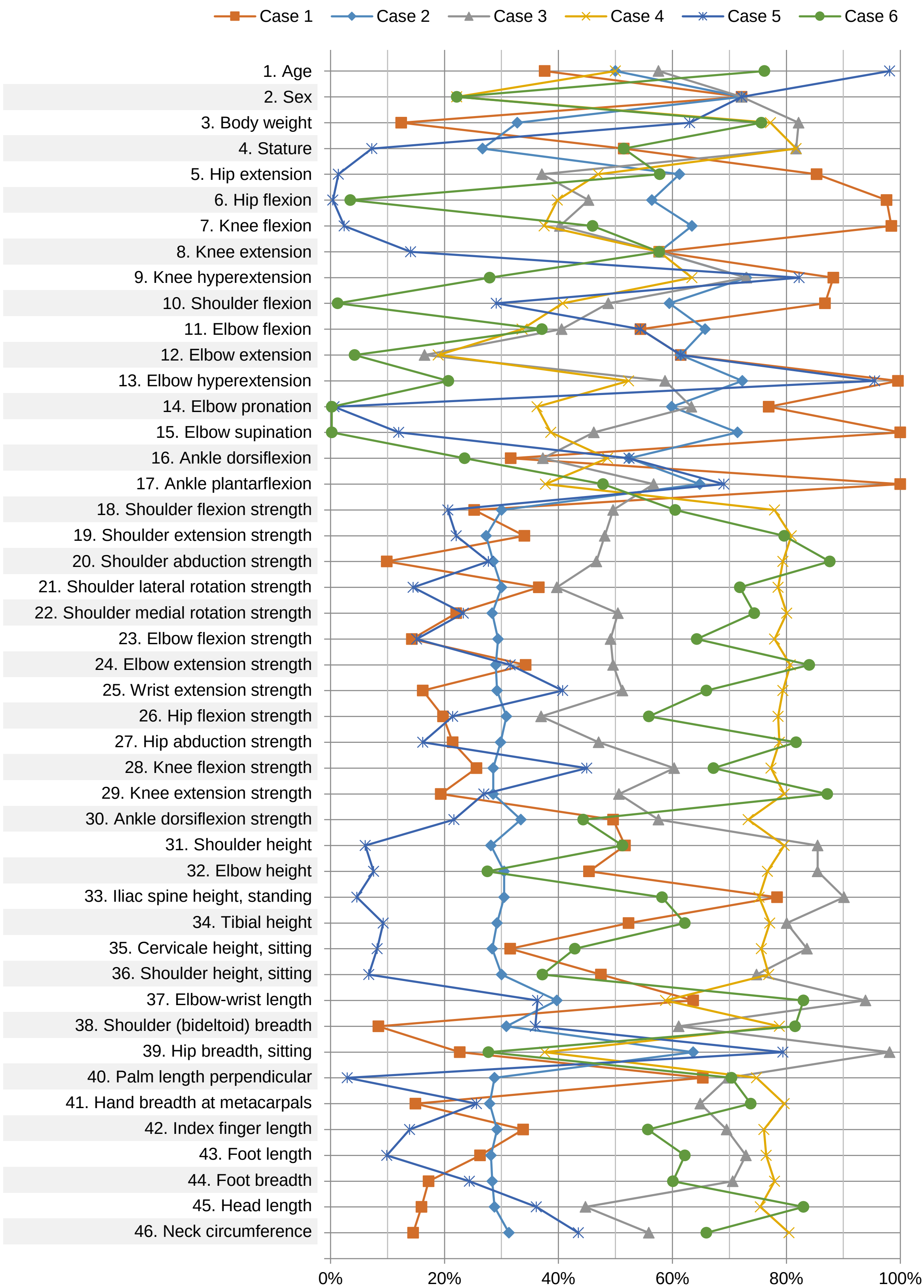

Figure 2 Visualisation of percentile values and percentile range for each variable and each case generated by the clustering algorithm (For percentile values of the variable sex: 75% is a female individual and 25% is a male individual)

To further evaluate the generated virtual test persons two of them were used as digital manikins in a dynamic simulation in IPS IMMA. In IPS IMMA the manikins were visualised as through a biomechanical model consisting of rigid links and joint centres. Maximum joint torques were calculated based on the joint strength and link length for each body part. Maximum joint torques and angles were then adjusted for each manikin. The simulation in IPS IMMA consisted of a case where the manikins were instructed to lift down a 5 kg oil tray from a truck. During the simulation, extreme joint angles and high joint torques were penalized and minimized through an ergonomic comfort function.

3. Results

The data for the generated virtual test persons were assessed visually, through so called percentile plots, to evaluate how the test persons represented the diversity of the synthesized population (Figure 2). These percentile plots enables evaluation of how big part of the diversity of the population that is considered, how well the generated test persons are spread throughout the distribution and if two or more test persons are similar. The results show that the cluster technique is able to produce distributed cases, of different age, gender, body size, ROM and strength, which covers a big part of the diversity of the population.

The visualisation of the virtual test persons in MakeHuman (Figure 3) shows that it is possible to quickly generate realistic looking digital models. When used in simulations the digital manikins shows difference in movements (Figure 4) and joint torque actuations (Figure 5) where a shorter and not so strong manikin is forced to use more of its strength and more extreme joint angles.

Figure 3 Visualisation of virtual test persons 4 and 5 as digital models in MakeHuman (MakeHuman, 2017)

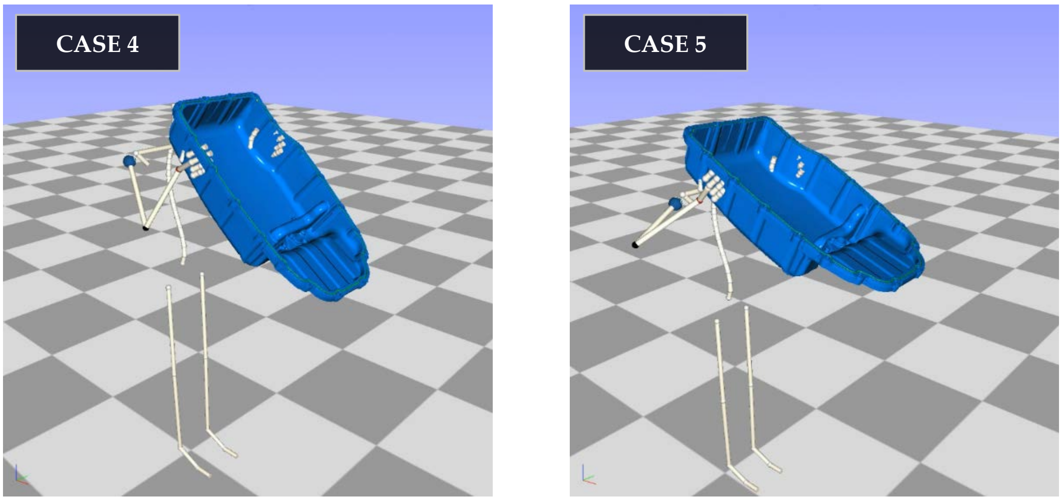

Figure 4 Visualisation and simulation of virtual test persons 4 and 5 as manikins in IPS IMMA

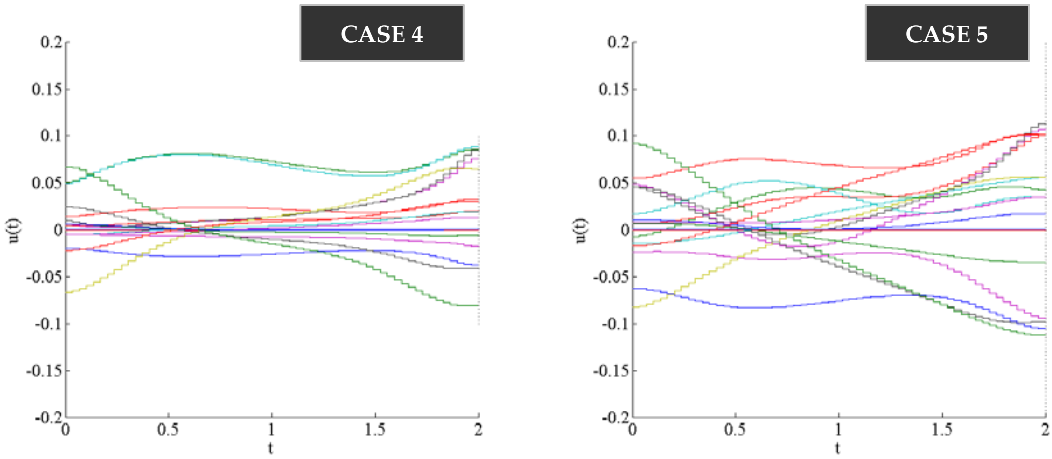

Figure 5 Visualisation of joint torque actuations during the simulation with manikin case 4 and 5 in IPS IMMA

4. Discussion

From the different visualisations of the generated virtual test persons it is possible to conclude that the methodology is able to produce data for virtual test persons that can be used within a digital human modelling software to consider not only diversity in body size but also strength and ROM. From the visualisation of percentile values and percentile range it is possible to conclude that the hierarchical clustering algorithm generates cases that are spread out over the distribution and thus considers a big part of the diversity of the population. No cases are very similar to each other and the cases are at the same time evenly spread out throughout the distribution. The generated and synthesized data is not representative for any real population since it is a mixture of data from different sources. It would be favourably if the original raw data could have been acquired from one and the same source for all 46 variables. However, few such comprehensive studies have been done and none is freely available, which indicates the need for more studies that considers body size, strength and ROM simultaneously. Still, the synthesized data is useful in this study to show the applicability of the method.

The use of cluster-generated virtual test person according to the presented method does not ensure that a certain percentage of the targeted population is accommodated. Still, as the cases can represent diversity in a range of user characteristics, they are argued to be valuable test cases during evaluation of design concepts. These more detailed test cases show that it is possible to achieve more realistic and accurate simulations, as strength and ROM data are included into the motion prediction algorithms used to generate motions in IPS IMMA. More accurate simulations with detailed data such as joint torque actuations enables more comprehensive evaluations of the biomechanical load but also point to the need for limits on such values.

5. Conclusions

Results from the study show that it is possible to use cluster analysis to generate data for virtual test persons that can be used within a digital human modelling software to consider not only diversity in body size but also strength and ROM. These more detailed test cases shows that it is possible to achieve more realistic and accurate simulations, as strength and ROM data are included into the motion prediction algorithms used to generate motions.

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