DINED Mannequin

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TOOLBOX

DINED Mannequin

Designing products that closely interact with the human body can be quite challenging. Think for example about wearables like helmets, (Virtual Reality-) goggles, masks, garments, sports braces, or shoes. We are all unique individuals and this requires designers to carefully consider the great variety of human body shapes and come up with smart ways of accommodating this variety in such products through the use of sizing systems, adjustable parts, or flexible materials (Verwulgen et al., 2018).

Toon Huysmans, Lyè Goto, Johan Molenbroek and Richard Goossens

A new form of anthropometry

To get more insight in human body variation, designers often rely on anthropometric data, preferably of their target population. Traditional anthropometric data describes body variation through a set of 1D body measurements, such as lengths, breadths, heights, and circumferences. They are usually comprehensively reported through tables of measurement percentiles indicating e.g. the smaller (P1), average (P50), and larger (P99) values of each dimension and defining the range to be accommodated by the product in order to serve most (e.g. 98%) of the population. The DINED platform provides such data through the '1D database'-tool (Molenbroek, 1999). Unfortunately, traditional anthropometric tables provide the designer with an oversimplified view of body shape, which is caused by sparsity of the measurements and the lack of describing the relations between measurements.

When measurement data is available at the level of the individual, it is possible to do correlation analyses to investigate the relation between body dimensions, e.g. through scatter plotting as in the DINED 'Ellipse'-tool (Molenbroek, 2015). Weakly or uncorrelated body dimensions often lead to more complicated sizing like for example breast size and chest circumference in bra sizing. Thus, although correlation analysis can significantly increase insight into the body shape variation, it remains a challenge to get a complete view of the body shape as the relative position of the dimensions is often unknown.

Advancements in sensor technology and 3D reconstruction techniques has led to affordable and accurate 3D body scanning systems becoming increasingly available. Some of these systems support virtual measurement of anthropometric dimensions, allowing extensive sets of measurements to be obtained efficiently. However, the full potential of 3D scanning is in the obtained surface description, providing a complete, point-by-point view of body shape. The analysis of body shapes using surface descriptions is what is studied in the field of 3D surface anthropometry which is an active field of research. Surface anthropometry has become increasingly popular, given its clear advantage, but it involves complicated data processing that has largely hindered widespread application.

We introduce 'Mannequin', a new tool for the DINED-platform. Through this tool, we want to make 3D anthropometry accessible for engineers, designers, and ergonomists by providing an intuitive interface for exploring 3D body shape variation and creating 3D design manikins. In the open data spirit of DINED, Mannequin can be freely used for both research and commercial purposes (Huysmans & Molenbroek, 2020).

Challenges of working with 3D scans

Nowadays, one can create a 3D body scan of an individual with the push of a button. The subsequent analysis of the 3D scan, however, remains a significant hurdle. This is partly due to the unstructured nature of the 3D scan mesh, which is a patchwork of triangles of various sizes connecting points on the surface of the body. Processing and analysis of such data, like changing the resolution, smoothing the shape, or taking virtual measurements, requires much more complicated algorithms compared to structured data analysis like with images, consisting of regularly spaced pixels on a rectangular grid. In addition, 3D scanners fail to capture occluded areas (arm pits and crotch area) and have difficulties reconstructing hair and small structures like the fingers and ears, resulting in missing data or holes in the mesh. Specialized mesh processing software exist, e.g., Meshlab (n.d.), Artec Studio (n.d.), and DesignX (n.d.), but they come with a steep learning curve and often a high price tag.

When moving from the analysis of a single body scan to an entire database of 3D scans, one is confronted with even more challenges and these cannot be addressed with currently available software packages. The reason is that meshes of different 3D scans cannot be directly compared, due to holes but also due to a difference in number, placement, and connectivity of the points and triangles. This is usually referred to as a lack of correspondence or homology. Before we can statistically summarize body shape variation present in the database, the 3D body scans need to be converted into a homological form. In such form, each 3D scan has the same number and connectivity of points and triangles and the points are placed at the comparable anatomical locations. In Figure 1, two example 3D scans and the principle of homology is shown.

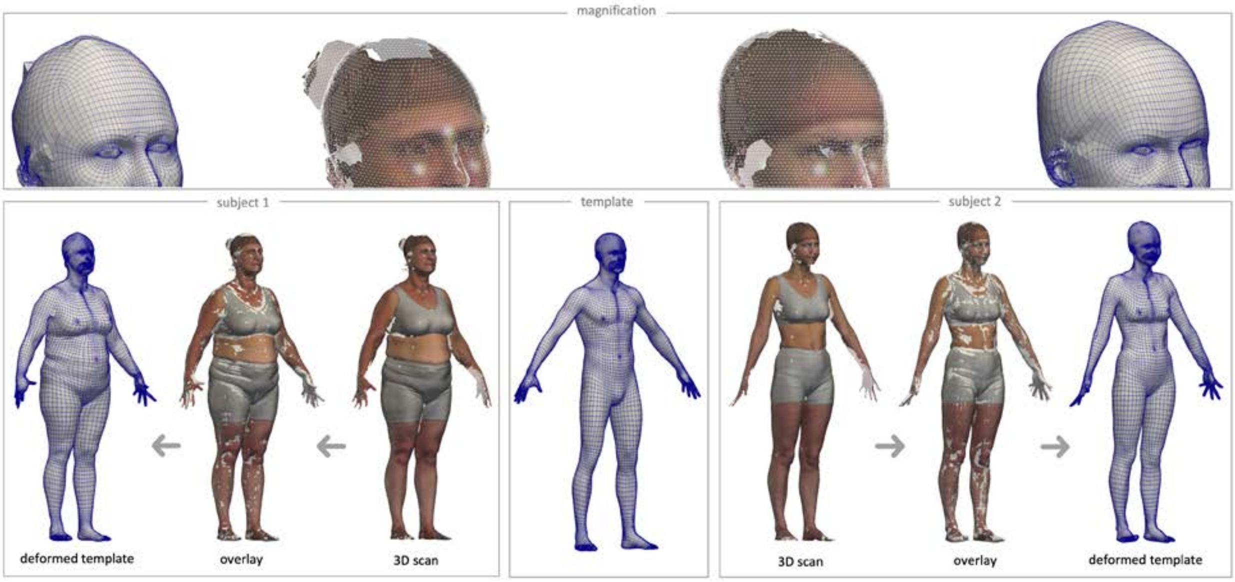

Figure 1. A necessary processing step in the analysis of 3D scan databases is the conversion of each scan into a homological mesh. The 3D scans of two subjects are shown (bottom left and right), together with the template mesh (bottom center) that is used to create a homological mesh for each scan. A magnification of the head area (top) shows various holes and differences in the mesh for the two original scans while these have been removed in the homological meshes.

Statistical analysis of shape

A study of the body shape variation for a specific target population usually starts from a database of 3D body scans, often complemented with a table of 1D physical measurements or virtual measurements derived from the body scans. As pointed out, the first step in analyzing a database of 3D scans is to obtain a homological representation of each scan in the database.

A popular approach to do this is deformable template registration (Danckaers et al, 2014). In this procedure, a homological form for each 3D scan is obtained by elastically deforming a common template mesh towards it, as demonstrated in Figure 1. In some cases, a set of anatomical landmarks has been identified for each subject which can be used to steer the template registration for optimal anatomical correspondence between the subjects in the database.

In contrast with traditional univariate (1D) anthropometric data, 3D surface anthropometric data is highly multivariate as homological body shapes consist of a large number, typically thousands, of 3D points. It is no surprise that the statistical analysis of such data requires more complicated techniques than those relied on in traditional anthropometry. Principal Components Analysis (PCA) is a popular technique to describe body shape variation. PCA is a dimensionality reduction technique that summarizes shape variation into a mean body shape and a small number, typically a few tens, of so-called shape modes. Figure 2 (pagina 6) visualizes the result of a PCA analysis for a Dutch population sample. This PCA model is also used to encode each individual 3D body shape into a small number of shape weights. By adding the weighted contributions of the different shape modes to the average body shape, the individual body shape is obtained.

While PCA is a helpful mathematical tool to compactly describe body shape variation and compactly encode individual body shapes, it can be a bit intimidating to non-engineers. We, therefore, intent to make the exploration of body shape variation more intuitive by involving the traditional 1D anthropometric measurements again. That is, we model the relationship between the 1D measurements of a subject and the subject's shape weights by a linear regression (Lacko et al., 2015). This allows the designer to explore (combinations of) 1D measurement percentiles and immediately see what 3D body shape corresponds to it. In this way, designers can use the familiar concept of percentiles, but also benefit the added value of 3D body shape.

An Online Analysis Platform

We integrated the concepts discussed in the previous section into a user-friendly online and open-data platform for 3D surface anthropometry, named DINED Mannequin (Huysmans & Molenbroek, 2020). The platform allows designers, without the need for an engineering background, to comprehensively explore 3D shape variation from a database of 3D scans and to create 3D design manikins that can be downloaded and further employed in computer-aided design software for product sizing.

Our platform consists of three parts. The first part comprises the processing and statistical shape analysis of the 3D scan database through the use of non-rigid registration and PCA. This part has to be executed offline in order to make the database available in the system. The second part, concerns the storage of the calculated models and traditional measurements table on a server and making it approachable via a web application programming interface. The interface provides functionality for retrieving measurement samples and regression models that relate the measurement percentiles with 3D body shapes. The third part is a user interface provided as a website. It consists of a population selection and specification panel, a measurement selection and manikin creation panel, a scatter plotting panel for exploring the data distribution and to view the position of the manikins in the population, a panel for interactive 3D viewing of the

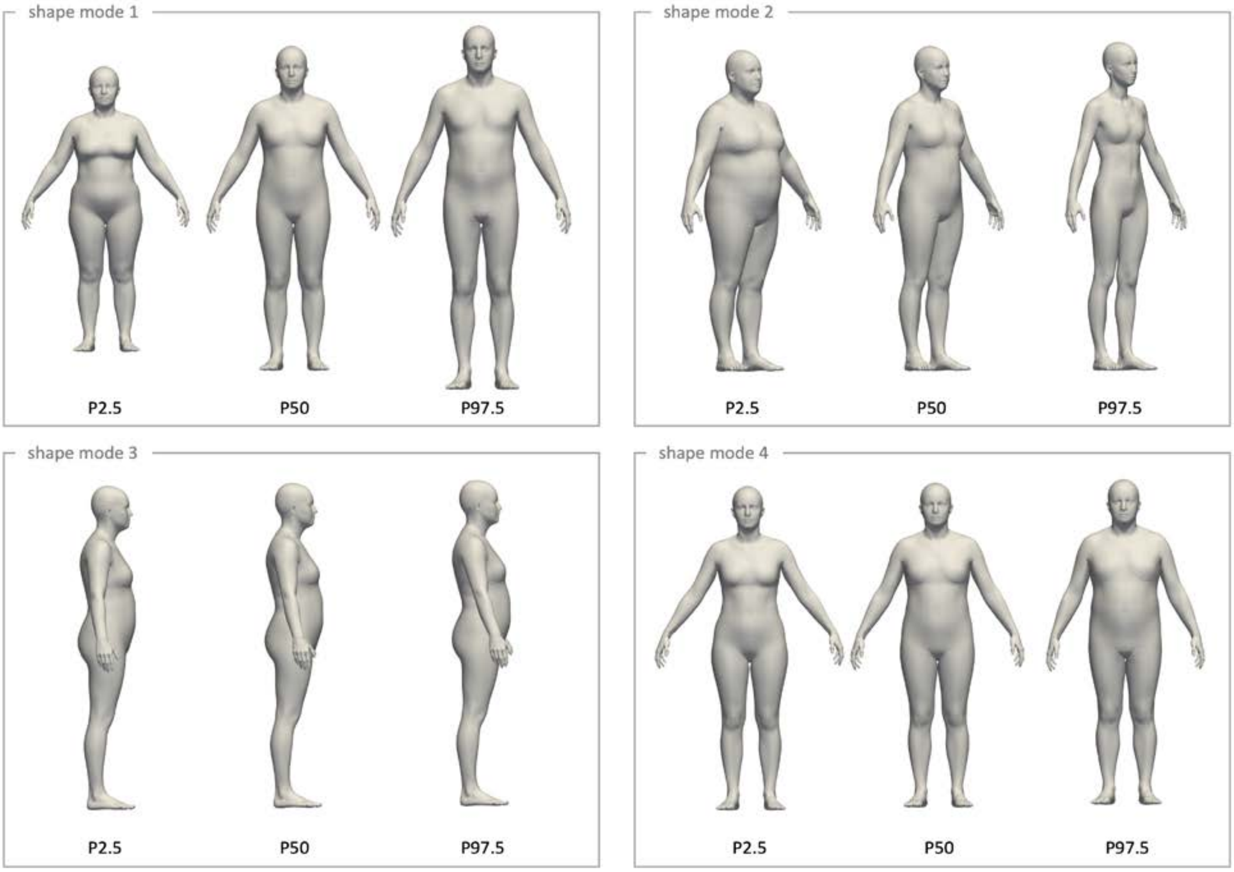

Figure 2. Visualization of the first four shape modes of the statistical shape model based on the Dutch subjects in the CAESAR dataset (mixed gender)(Robinette et al., 1999). For each mode, three percentiles are shown: P2.5, P50 (mean), and P97.5. The first mode explains body size and shows a correlation with gender. The second mode is related to the body mass index. The third mode mainly explains posture differences and the fourth mode is a combination of posture differences and gender.

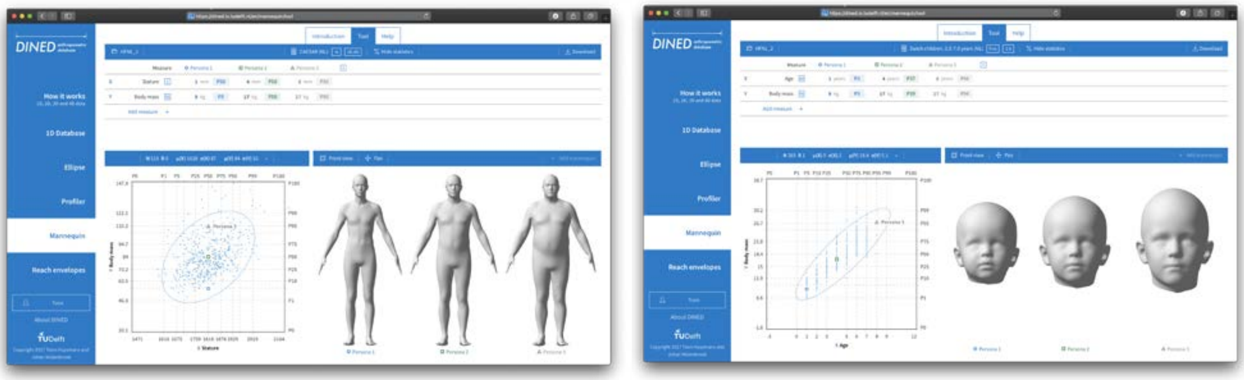

Figure 3. Two 3D anthropometric analyses with the DINED Mannequin web platform. Top: Variation in body mass with a fixed stature for the male population, derived from the CAESAR database (Robinette et al., 1999). Bottom: growth of the head with increasing age and body mass, derived from the database of Goto et al. (2019).

manikins, and a module to download manikin data, scatter plots, and STL-files of the manikins. Some screenshots of the DINED Mannequin tool are provided in Figure 3.

Application

The Mannequin platform, which maintains an open-data policy, is realized as an extension of the DINED-website and available at http://dined.io.tudelft.nl. A Dutch child head population and a Dutch full body population is available, based on a TU Delft database (Goto, Molenbroek, Cabo, and Goossens, 2019) and the CAESAR database (Robinette, Daanen, and Paquet, 1999).

The applicability of the DINED Mannequin platform is demonstrated by the work of Staal, Huysmans, and Molenbroek (2019). They used the Dutch male database to set up a sizing system for a wetsuit and create a 3D design manikin for each size as shown in Figure 4. They then designed an M-size wetsuit in a textile design software (CLO3D, n.d) based on the medium size design mannikin and digitally evaluated and after prototyping also physically evaluated the wetsuit design (see Figure 5). They concluded that 3D anthropometric analysis in combination with virtual textile design software allows a designer to develop a good fitting wetsuit in very short time-span.

Conclusion

We envision the DINED Mannequin platform as an open-data hub for researchers to share their 3D anthropometric studies of external and internal (e.g. bone) body shape of various target groups, like obese, elderly, and children, and for designers to intuitively explore body shape variation in the design of consumer and medical products.

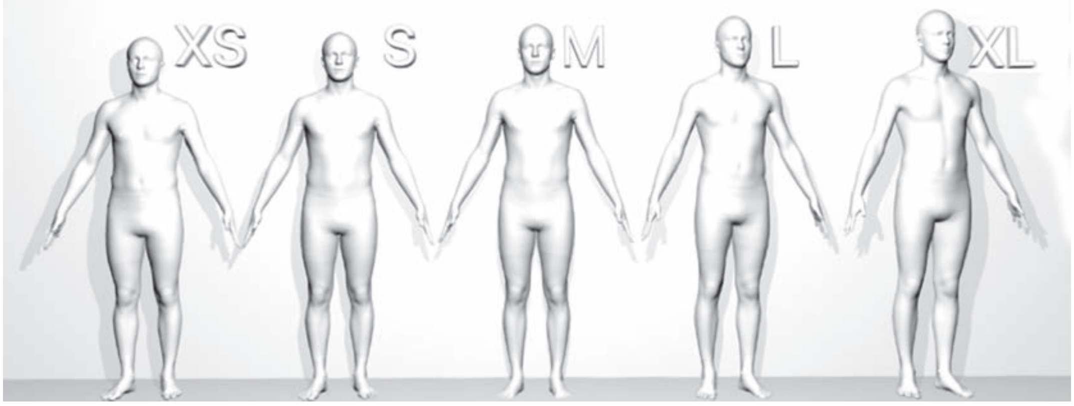

Figure 4. Design manikins forming the basis of a wetsuit sizing system for males (Staal, Huysmans, Molenbroek, 2019).

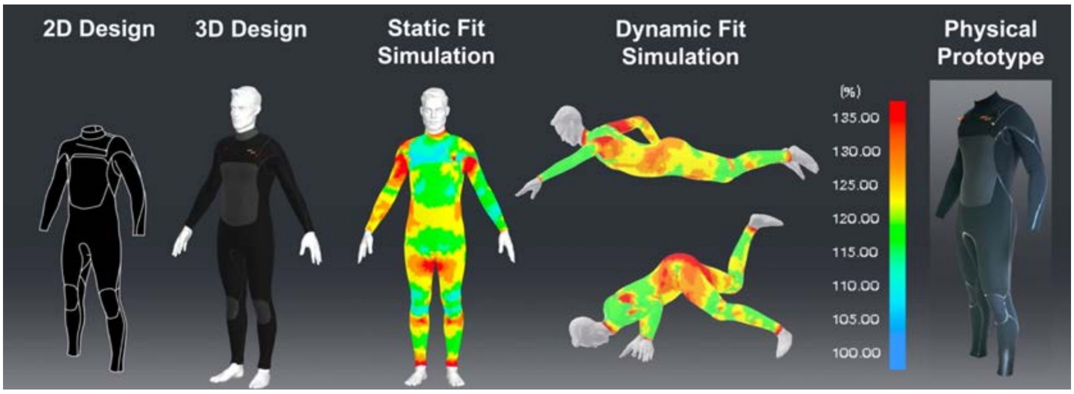

Figure 5. Design of a wetsuit on a size M manikin using CLO3D. The color map indicates the amount of stretch in percentage (100% indicates no stretch). For a wetsuit a certain level of stretch is required to avoid water from entering the suit (Staal, Huysmans, Molenbroek, 2019).

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