ANTHROPOMETRICS 2.0: ENRICHMENT OF CLASSICAL ANTHROPOMETRY THROUGH MULTIDISCIPLINARY COLLABORATION

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ABSTRACT
State of the art computational methods might offer the opportunity to handle 3D anthropometrical information: in a collection of similar 3D shapes, when there is a correspondence of points, certain mathematical operations, such as calculation of mean shape and even a standard deviation in each point, can be performed. As such, a statistical shape model can be interesting for the purpose of product development since it provides insight in the intrinsic variation of a 3D form within a given population and-if large enough- even contains all information to determine the shape of each individual, making statistical shape models potentially very interesting to design mass customization products. To that end, the information contained in statistical shape models should be made available for the purpose of product development, to enrich the classical use of anthropometry in the design process. The intended enrichment is further denoted "Anthropometrics 2.0". This concept was first explored through a multidisciplinary collaboration with master students in Product Development, Computer Science and Applied Engineering, supported by the Belgian industrial research and development conglomerate (BiR&D).
The objective of this educational project was to explore how state of the art statistical shape models could be made available as digital models for the purpose of product development through CAD. In this paper we present the results towards this aim and how the different scientific disciplines with respective master student collaborated towards this purpose. The project was confined to the human head.

Keywords: Anthropometry, statistical shape models, CAD, multidisciplinary collaboration

1 INTRODUCTION

No two humans have the same body and the average human does not exist [1]. This makes designing products that optimally fit the human body a challenging task. For years, 1D anthropometric measurements such as height, width and circumference have been used to anticipate the necessary customization for near-body products. However, since these measurements do offer only very sparse statistical information, several iterations of user testing and feedback integration are often required. 3D statistical shape models could offer a solution for this problem [2]. Shape models consist of 3D geometric surfaces with a large number of corresponding points [3]. This makes it possible to combine classic 1D measurements with a detailed local and global analysis of shape variation for various body parts. In theory, this enables designers to generate and compare realistic shapes using intuitive anthropometric parameters. Several studies have shown viable methodologies for this purpose [4], some of which have developed preliminary tools for designers [5]. However, it has never been demonstrated to work in real-time in a contemporary CAD environment that is familiar for the users.
One of the reasons for this is the inter-disciplinary nature of the problem. On the one hand, computer scientists or mathematicians are needed to perform the statistical analysis and create the initial 3D shape models. On the other hand, the shape models need to be incorporated into a CAD-environment. Lastly, they need to be evaluated by the end users, i.e. product designers.

This educational project set out to realize a proof-of-concept for a statistical shape model of the human scalp, created during the PhD of Daniël Lacko [6]. The shape model was created from a sample of 100 MRI-scans, from which the skin layer was segmented and the region of interest was selected based on a manually determined boundary. The skin surfaces were then corresponded (see figure 1), PCA was performed to find the global and local variations and the correlation between the PC weights (see figure 2) and seven anthropometric measurements was examined. It was found that the global shape of the human scalp could accurately be predicted using these measurements as parameters.

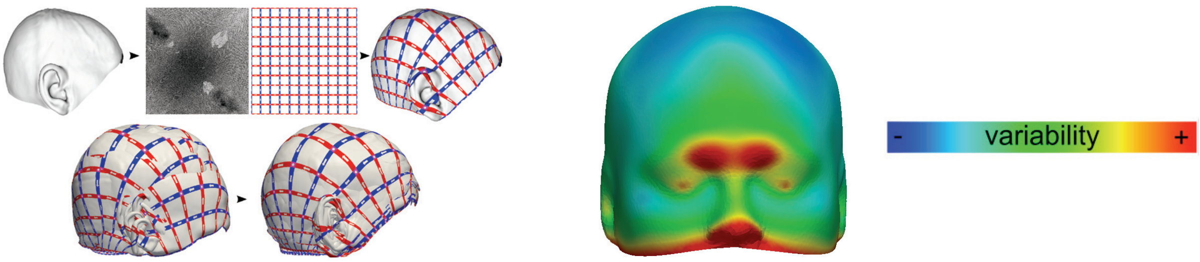

Figure 1. Building of a statistical shape model from medical images (left): a collection of head forms is retrieved from MRI images, annotated and mapped to coordinate grids, and aligned. As a result e.g. a mean shape with the variation at each point can be visualized (right)

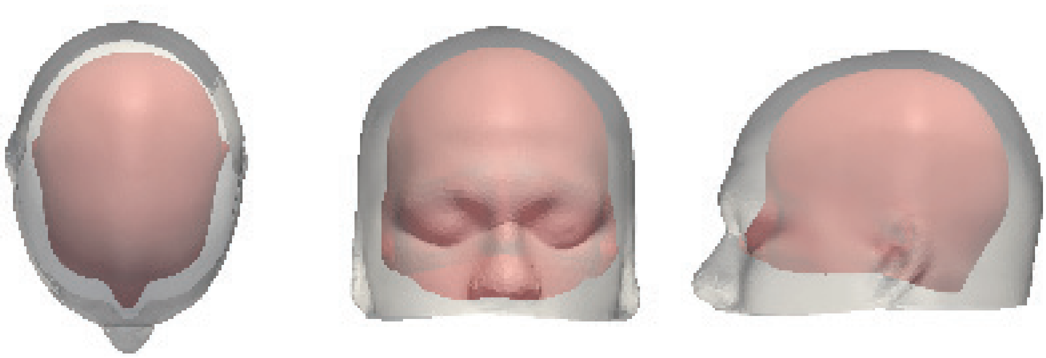

Figure 2. Mean head with first principal component added +3 and - 3 times standard deviation [7]

The goal of this project was to implement this parametric shape model in a CAD software package by recruiting an interdisciplinary team of students. The hypothesis was that their combined skillset would make this ambitious goal possible. Students from the fields of Product Development, Computer Science and Applied Engineering were selected and each was expected to perform a specific part of the implementation for their master's thesis. The Applied Engineering student was asked to automate and improve the segmentation process, in order to make adding new scans to the model more efficient. The student from Computer Science was to create a plug-in for CAD software in which the shape model could be interacted with in real-time. The Product Development student's assignment was to evaluate the user interface and user experience of such a plug-in and to create a simple head-mounted design using the shape model. Each student was guided by an expert in their specific field, as well as by the team that created the original shape model. The students were encouraged to collaborate as much as possible and to clearly communicate their work process and results to each other.

2 MATERIALS AND METHODS

The project was conducted with the support of the Belgian Industrial Research and Development fund (BiR&D) that stimulates multidisciplinary collaboration to enhance industrial relevance of research and educational projects. Three research groups of the University of Antwerp worked together: Vision Lab (Physics), Cosys-Lab (Applied engineering) and Product Development, each group guiding a respective master student from Computer Science, Applied Engineering and Product Development.

The aim of the project was to make state of the art statistical shape models available for the purpose of product development by building a CAD environment in extension to anthropometric distributions and existing digital mannequins.
For the CAD environment there was opted to use SolidWorks© due to expertise by the participating student as well as by the supervising team, access to consultancy, and availability of licenses.
Each of the students started along the initial project plan of the BiR&D proposal that was written by the supervising research teams, starting with an initial literature study required to execute his or her task in the project and further acquisition of additional tools and techniques during the course of the project. In addition, students made a detailed project plan to assign individual tasks and responsibilities. Head shapes of an ongoing PhD research [6] were incorporated in SolidWorks© and each model was accessible for an individual design. The outcome was an intuitive parameterized CAD model of the scalp shape. As such, a parameterized design could be constructed. The use of the enriched CAD environment as a tool for additive manufacturing was verified through designs and rapid prototyping and communicated by the development of a demonstrator case.
The project team was guided in regular meetings around major milestones: kick-off, implementation plan, intermediate progression, mid-term review, anthropometric model implementation, plug-in operation and final presentation. Each student presented his of her progression, followed by feedback from the project team to discuss further steps, synchronization of deliverables and to enhance mutual understanding. Information was exchanged by file sharing (Dropbox), electronic communication (email) and telecommunication (cellphone and Skype). In addition, students where followed up by their respective domain specific (co-)promotor complemented by other members of the supervising team, if required.

3 RESULTS

3.1 Contribution from computer science

The student from computer science wrote an extensive overview of relevant mathematical theories and techniques: statistical shape modelling, fitting of a cloud of points with B-splines, principal component analysis, linear equation solving, matrix decompositions and linear feature mapping. She got acquainted to the basics of SolidWorks© and mastered all software required for the successful realization of the SolidWorks© plugin.
The plugin was tested using the statistical shape model of an ongoing research project, consisting of 105 surfaces retrieved from medical images and 7 standard anthropometrical measurements already annotated: *head length*, *face width*, *bitragion width*, *ear height*, *horizontal position of the ear*, *vertical position of the ear* and *projected ear height* [7], further denoted "the anthropometric model".
However, it is possible to use other input databases for improved accuracy, for example with an extended number of shapes and/or additional anthropometrical measurements. By using a uniform mathematical entity such as a B-spline, the designer becomes able to define useful and clear geometrical relations between an individual's surface and its digital design and hence can produce smart designs suited for mass customization.
Computational complexity was managed by clever use of mathematical properties such as linearity of principle component decomposition [8] and linearity of the anthropometric model, the use of sparse matrices, good linear equation solving techniques and maximal use of affine invariance of B-spline fitting.

3.2 Contribution from computer applied engineering

The student from Applied Engineering first performed a preliminary study on the techniques to detect and correct artefacts (e.g. holes and spikes) typically arising in CT, MRI and laser scans, using an underlying statistical shape model to reconstruct the original shape, such as Poison reconstruction [9], model and elasticity regularization [10].
She implemented and compared three error correcting algorithms based on a given statistical shape model that, at the same time, extend the statistical shape model with the corrected shape: a first fitting strategy where the shape model is regularized, a second fitting strategy where the elasticity parameters of approximating forms are regularized and a third, combined technique. The input data of her algorithms are: 1) a shape of the human head possibly contaminated with artefacts, for example an outer surface extracted from an MRI scan and 2) a statistical shape model of similar but

uncontaminated forms. The output data of her algorithms are: 1) a proposed reconstruction of the original shape and 2) a correspondence of the reconstructed shape with the shapes of statistical shape model.

The shape reconstruction was validated for artefact removal in numerical experiments with dramatic holes in the skull, as shown in Figure 3. Thereby the model regularization (left) and combined strategy performed equally well, where elasticity regularization (middle) is unsuitable, mainly due to an inherent problematic alignment in the initial step of the algorithm.

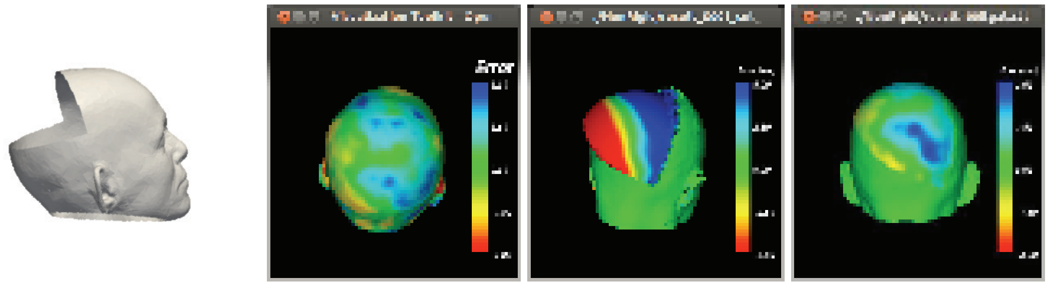

Figure 3. reconstruction of missing information in head shapes (left) with three shape reconstruction algorithms

3.3 Contribution from product development

The student from Product Development focused on the merits of statistical shape models when used in a regular product development process, as described e.g. in [11]. Firstly, relevant economic and technologic factors concerning the intended implementation and intended use of statistical shape models in CAD were explored, to end up with the specifications for a CAD environment enriched with information retrieved from statistical shape models. Secondly the actual plug-in developed by Computer Science was verified by designing artefacts that ought to closely fit the human head (Figure 4) and by building prototypes of these artefacts. Verification was done with physical models realized with a Dimension 1200 3D printer with an accuracy of about 1/4th of a mm. The student designed the model displayed in figure 4 (left) on his own head, on an image retrieved from an MRI scan. A very good fit was achieved. Furthermore, a method to validate the representativeness of the database with rapid prototyping was developed: screws in model were used to measure variations in the band from glabella to ophistokranion (at points A, B, C in the middle of Figure 4) and a measurements in 8 test persons holt indeed magnitudes predicted by the statistical shape model (Figure 4 middle).

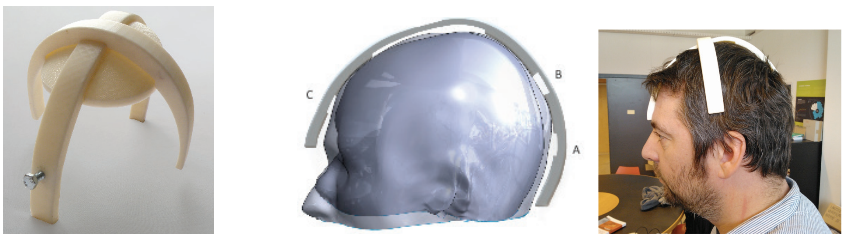

Figure 4. An instrument to measure variations on the human head (left) developed as a personalized design for and by the student, and points that were measured (middle right) by other subjects Stijn Verwulgen, right)

The band from glabella to ophistokranion was mapped on the head shape models of Daniël Lacko and Stijn Verwulgen (Figure 5), retrieved from the same batch of MRI images and fitting was physically verified through 3D printing.

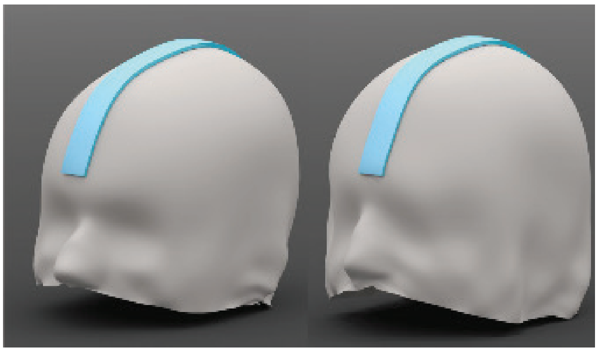

Figure 5. Personalized form following the models for the heads of Daniël Lacko and Stijn Verwulgen

In addition, the student constructed a demo to communicate the idea of a parameterized design based on the human head. In his example displayed in figure 6, on the left the design is seen: the device on top and on the left and the right are tailored to an individual's head whereas the bended bars have a fixed form and size. When the head shape is altered e.g. by reducing the length value of the head, the most probable corresponding shape is automatically rendered together with the respective personalized design (Figure 6 middle and right).

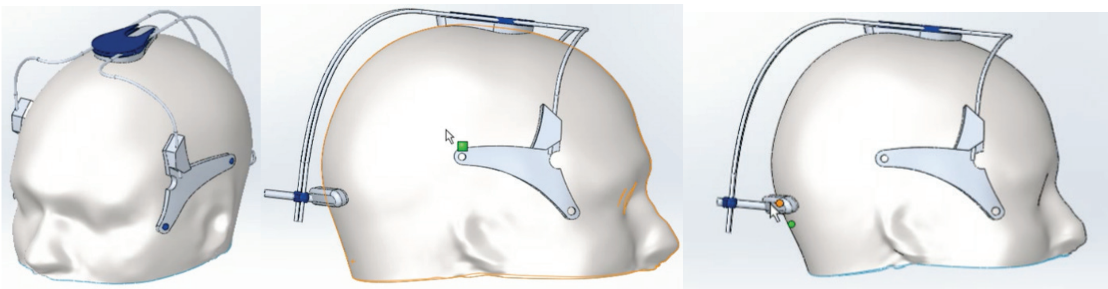

Figure 6. Demonstrator case of a personalized design

4 CONCLUSION

The inter-disciplinary team succeeded in developing a CAD plug-in for anthropometric shape modelling. Despite the strict time constraints, the plug-in could be used to create an elementary individualized head-mounted design for two supervisors.

The student from Computer Science wrote a plug-in to make statistical shape models of the human head and the anthropometric model available in an enriched CAD environment for the purpose of product development. The software was verified with an input database of 105 models and 7 standard anthropometrical measurements. The input database can be extended if additional shapes or feature data becomes available to refine the models in the enriched CAD environment. She is currently pursuing a PhD in an unrelated field.

The application is still in early development, yet it gives a good indication of the functionality of designs that are directly parameterized on the human body using straightforward anthropometrical measurements as parameters. Though the software is currently only available internally, the project managed to arouse interest from the industry and resulted in a BiR&D award (http://www.birdbelgium.com/call2012). Funding for further research on PhD-level has been awarded in the form of an IWT-TETRA project "CADANS: A CAD Platform for 3D Statistical-Anthropometric Design" (IWT ref. 130771). This project will be executed by a multidisciplinary team of product developers and computer scientists.

The student from Applied Engineering constructed an artefact removal algorithm that allows for an efficient automated reconstruction of original shapes, directly from medical images, thereby omitting labour intensive extraction of representative images by hand on an individual basis. The algorithm allows for an efficient extension of current statistical shape models concerning automated shape reconstruction and yields a promising approach towards automated acquisition of anthropometric measurements. She is now continuing her work in a PhD at the Vision Lab of the University of Antwerp.

The student from Product Development identified specifications for an enriched CAD environment based on statistical shape models. The current implementation was tested for design for additive manufacturing by the design of demos and verified with rapid prototyping, followed by recommendations for further improvements. He is currently employed in a paid internship in Spain.

These results clearly show the added value of interdisciplinary collaboration in education. Universities benefit from additional research projects, which might otherwise not have been realized. The industry benefits from clear applications and possibilities for further collaboration with universities. Finally, but perhaps most importantly, the students benefit from the broadening of their knowledge, get a first taste of different academic research fields and can add an ambitious project to their résumé.

The results of this project at master level have revealed the potential of a new design technique that has been further developed through research. Moreover the project serves another educational purpose: results have been presented to master students in product development, as an invitation to use the new technology in their design projects.

The authors therefore encourage other universities to employ master or even bachelor grade students for the integrated validation of research projects from different fields, with a focus on the development of new design techniques.

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