Applied Ergonomics 48 (2015) 70–85

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Evaluation of an anthropometric shape model of the human scalp

Daniël Lacko [a, b, c, *], Toon Huysmans [a], Paul M. Parizel [d], Guido De Bruyne [b], Stijn Verwulgen [b], Marc M. Van Hulle [c], Jan Sijbers [a]

[a] iMinds-Vision Lab, University of Antwerp, Antwerp, Belgium
[b] Product Development, Faculty of Design Sciences, University of Antwerp, Belgium
[c] Laboratorium voor Neuro-en Psychofysiologie, KU Leuven, Leuven, Belgium
[d] Department of Radiology, Antwerp University Hospital & University of Antwerp, Antwerp, Belgium

A R T I C L E I N F O

Article history:
Received 9 May 2014
Accepted 17 November 2014
Available online 6 December 2014

Keywords:
Computer-aided design
Shape modeling
Anthropometry

A B S T R A C T

This paper presents the evaluation a 3D shape model of the human head. A statistical shape model of the head is created from a set of 100 MRI scans. The ability of the shape model to predict new head shapes is evaluated by considering the prediction error distributions. The effect of using intuitive anthropometric measurements as parameters is examined and the sensitivity to measurement errors is determined. Using all anthropometric measurements, the average prediction error is 1.60 ± 0.36 mm, which shows the feasibility of the new parameters. The most sensitive measurement is the ear height, the least sensitive is the arc length. Finally, two applications of the anthropometric shape model are considered: the study of the male and female population and the design of a brain-computer interface headset. The results show that an anthropometric shape model can be a valuable tool for both research and design.

1. Introduction

Parametric shape modeling is a popular technique to describe a population of 3D shapes with a limited set of parameters (Wang, 2005). When applied to the human body, it enables medical doctors, product designers and researchers to study the human body through high-quality 3D representations (Magnenat-Thalmann et al., 2004). For the sake of simplicity, people working in these fields will be referred to as 'ergonomists' throughout the remainder of this article. The parameters that yield the most accurate shape predictions of the body are usually found by statistically analyzing a sample of 3D polygonal surfaces. Although the resulting statistical shape models (SSM) accurately describe the object's shape, these statistics are often difficult to interpret and non-intuitive for design specialists. Therefore, several methods have been proposed to compute a new set of parameters to characterize the human body shape. Most of them were focused on the full body (Allen et al., 2003; Wang, 2005; Chu et al., 2010; Baek and Lee, 2012; Wuhrer and Shu, 2012), the face (Blanz and Vetter, 1999) or head (Xi and Shu, 2009). This research shows that head shapes can indeed be predicted from either semantic parameters such as age, gender and ethnicity or from various body size measurements.

While more recent techniques were suggested as solutions for industrial designers (Meunier et al., 2000; Niu et al., 2009; Xi and Shu, 2009; Baek and Lee, 2012), it is not clear how they should interpret and use the results. Custom GUI applications have been suggested, in which the model can be varied according to statistical parameters (Meunier et al., 2009; Zhuang et al., 2013). However, statistical parameters are not intuitive enough to be used by ergonomists. Other suggestions include generating 3D models based on anthropometric measurements and then using these static shapes in 3D software (Lin and Wang, 2012), which is not far off from traditional anthropometry. Furthermore, only the average geometric (i.e. vertex-to-vertex) fit of the shape models to the scanning data was usually validated. While this is a valuable parameter, it only gives a very limited indication of the predictive capabilities of the models. Finally, despite the advent of head-centered products such as EEG-recording devices (Allison et al., 2012), to the best of the authors' knowledge no parametric models to date focus on the scalp.

In this work, a statistical 3D shape model of the human scalp is created and a linear mapping is made between statistical parameters and ten anthropometric measurements. The prediction accuracy of the model is examined by using three different error metrics, i.e. vertex-to-vertex, normal and tangential error. Both the

* Corresponding author. iMinds-Vision Lab, University of Antwerp, Antwerp, Belgium. Tel.: +32 32652472; fax: +32 32652245.
E-mail address: daniel.lacko@uantwerpen.be (D. Lacko).

http://dx.doi.org/10.1016/j.apergo.2014.11.008
0003-6870/

average and point-to-point errors are evaluated for several combinations of anthropometric measurements. Cross-validation is used to verify both the statistical and the anthropometric shape model. The sensitivity the prediction to measurement errors for individual parameters is shown and the effect of measurement errors on the prediction is evaluated. Such extensive analysis will allow ergonomists to select the minimal required set of anthropometric measurements, determine the influence of measurement errors and accurately locate shape variation.

The remainder of this paper is organized as follows. Section 2 describes how the shape model is built, including the segmentation and parametrization of the MRI scans, the principal component analysis (PCA) of the 3D scalp geometry, the selection of the anthropometric measurements, and the correlation between these measurements and the PC weights. In Section 3, the shape model is evaluated in terms of prediction accuracy, the data set size is verified for the statistical as well as the anthropometric model, and the sensitivity of the prediction to measurement errors is discussed. The results are shown in Section 4, as well a discussion on how to select the right anthropometric measurements and an application for anthropometric research and for industrial design. Finally, the conclusion is formulated in Section 5.

2. Methods

This section presents the workflow of the methodology that was used to create the anthropometric shape model (see Fig. 1). Because the input MRI scans contain more information than just the skin surface, they first need to be preprocessed to remove all artefacts and to extract the cranium surface as a geometric surface mesh. This process is described in Section 2.1.1. The surfaces then need to be aligned to each other and be projected into a simpler parameter space for further analysis. This ensures that corresponding points are used throughout the remainder of the methodology, instead of possibly comparing e.g. the tip of the nose with the tip of the earlobe. Section 2.1.2 describes how this was done. The surfaces are then sampled so as to obtain a uniform set of corresponding points on which PCA can be performed to examine the shape variation, as explained in Section 2.1.3. However, as will be discussed in Section 2.2.1, PCs are not intuitive enough to be used as parameters for the model. Therefore, Section 2.2.2 concludes the methodology by showing how ten intuitive measurements can be used instead to analyze the head geometry and predict new head shapes.

2.1. Building the shape model

2.1.1. Segmentation of MRI scans

100 MRI T1-FFE-weighted MRI scans (50 male, 50 female aged between 20 and 30 years, Western population) were used as input for the shape model. The scans were acquired using a Philips ACS III 1.5 T scanner in the sagittal acquisition plane, with a slice thickness of 1 mm, an echo time of 10 ms, a repetition time of 18 ms and a flip angle of 30°. These scans were obtained from the International Consortium for Brain Mapping (ICBM) database (Capetillo-Cunliffe et al., 2007).

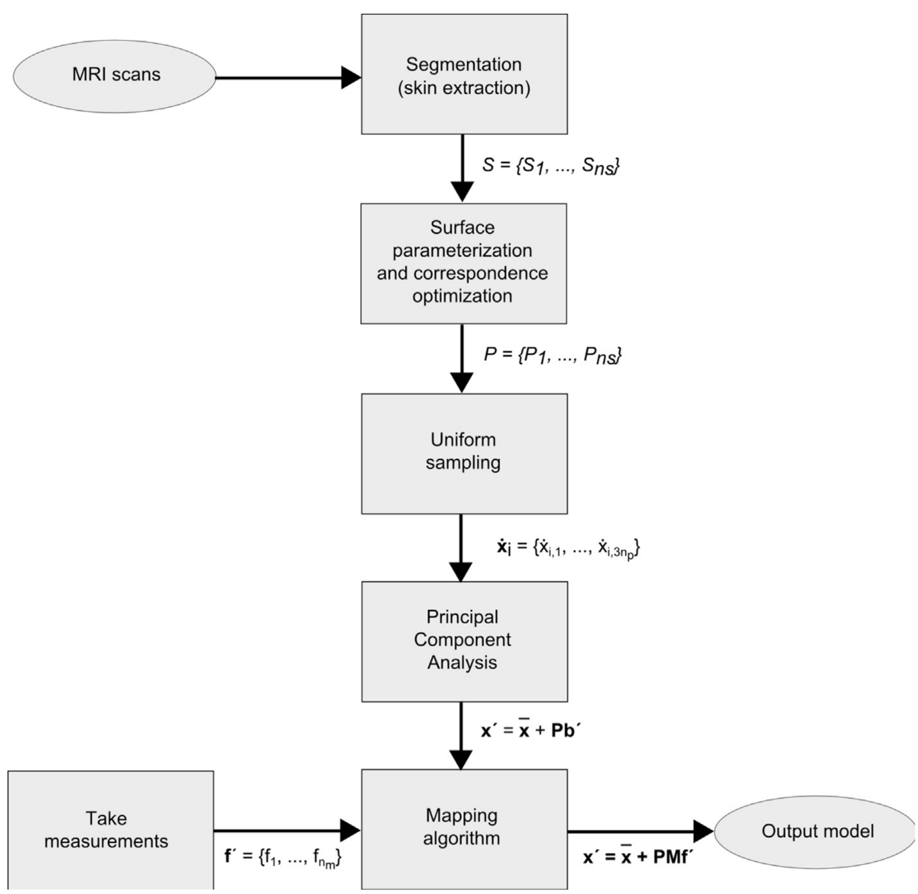

Fig. 1. Workflow. The skin layer is first extracted from MRI scans, then the scalp surfaces are parameterized and corresponded to one another. After sampling the images using uniform landmark locations, PCA is performed on the resulting point cloud. Finally, the anthropometric measurements are acquired from the scalp surfaces and are correlated with the respective PC weights to create a mapping. This mapping results in an anthropometric model that can be used to predict new scalp surfaces based on anthropometric measurements.