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Beyond Digital Human Body Atlases:
Segmenting an Integrated 3D Topological Model of the Human Body

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ABSTRACT

The use of integrated models of the human body in three-dimensional environments enables the study of the anatomic structures with a high degree of interactivity and detail. The geographical information systems approach in building topological models allows overcoming certain limitations found in anatomical atlases. In this study, an integrated (vector-raster) 3D model, which defines the external surface of the human body, is expanded by adding the corresponding anatomical structures. The reconstruction of the anatomical structures begins with their segmentation, performed on transverse RGB images of the body. The expanded model, built with explicit topological features, enhances the functionality of the input model by optimizing the identification function and developing an inclusion analysis in 3D. The features of the expanded model allow exploring more efficiently the human body information and representation.

KEYWORDS

3D GIS, Anatomical Atlas, Anatomical Structures, Human Body Representation System, Integrated Model, Segmentation, Spatial Analysis, Topology

INTRODUCTION

Anatomical atlases have been used to represent, explore, and study the human body. Since representations, such as "De Humani Corporis Fabrica" from year 1543 (Vesalius, 1998), to current atlases (Netter, 2014; Paulsen & Waschke, 2013), there was a great evolution in terms of reliability, quality, quantity and diversity of the presented information.

The emergence of the technologies for acquiring data of the human body and the increasing computer performance, allowed the development of digital atlases in which it is possible to integrate different sources of information and to develop tools that enhance the interactive exploration of 3D models (Argosy Publications, 2008; Biodigital Human, 2013).

Current digital systems based on non-topological models present limitations concerning the spatial analysis capabilities (António Barbeito, Cabral, Painho, & O'Neill, 2014). Thus, the representation of the human anatomy can benefit from the use of 3D topological models (4D, when modelling temporal phenomena is necessary). Advantages of topological models in representing anatomical structures have been already demonstrated in some studies (Martone et al., 2008; Zaslavsky, Baldock, & Boline, 2015; Zaslavsky, He, Tran, Martone, & Gupta, 2004).

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Since the information regarding the human body is a type of geographical information, the use of geographical information systems (GIS) can be considered to build anatomical atlases. For this purpose, it is essential that GIS improve some features of the existing applications, such as:

- The ability to integrate data from different sources, e.g., raster and vector data;
- The possibility of using spatial analytic functions associated with topological models. For instances, current digital anatomical atlases allow querying databases but, contrary to GIS, they have difficulty in performing analysis based on spatial relationships, e.g., neighborhood and inclusion analysis;
- The high level of interaction with the geometric components of the model;
- The ability to develop applications within a single working environment to solve specific problems.

Assuming the interest of this approach, the main objective of this paper is to improve an initial model of the human body by using GIS capabilities, i.e., providing a GIS topological model of the human body embedded in a graphical user interface (GUI) with the appropriate functionalities. The final system should provide the type of information found in the anatomical atlases and overcome some of its limitations. This goal is subdivided in 4 sub-objectives: (i) to develop a semi-automatic segmentation method that takes advantage of the specificity of the input data; (ii) to update the GIS model with the segmented structures; (iii) to integrate the model in a graphical interface provided with navigation, identification and visualization tools; (iv) the development of a spatial analysis tool based on the containment information of the updated model.

In the next section, we detail the related work about digital atlases found in the literature. Subsequent sections are dedicated to describe data, present conceptual models and procedures, present and discuss results, and draw conclusions about this study.

RELATED WORK

Since the appearance of the Visible Human projects (Visible Human Project (VHP) (Spitzer et al., 2004), Chinese Visible Human Project (CVH) (Zhang, Heng, & Liu, 2006), and Visible Korean Human (VKH) (Park, Chung, Hwang, Shin, & Park, 2006)) different approaches have been used in the segmentation of anatomical structures on axial images. Leaving aside purely manual operations, the segmentation methods can be classified as semi-automatic or automatic. As semi-automatic methods (Imelińska, Downes, & Yuan, 2000), (Beveridge, Minhua, Rea, Bale, & Anderson, 2013) require the intervention of an operator, the high volume and complexity of data justify the research works that propose automatic segmentation methods (Li et al., 2014; Xue, Antani, Long, Demner-Fushman, & Thoma, 2014). However, errors are inherent to segmentation procedures. For example, the algorithm presented by (Xue et al., 2014), leads to an overall accuracy of 98.8% for computed tomography (CT) imaging and 99% for cryosection images. According to (Wu et al., 2012), after the primary segmentation, the main errors that are produced include the segmentation error and the segmentation missing. Intra-observer variation between experts is also referred. Thus the complexity and the inevitability of errors in segmentation procedures is clear. The existence of errors, even if they are small, shows that the supervision and human intervention are not negligible. In many cases, the tolerance to segmentation errors can be related to the further use of the obtained results. For example, if the results are used to reconstruct three-dimensional models, a single wrong pixel outside the segmented structure, can lead to a highly deformed anatomical structure. In this particular case, it is absolutely necessary to eliminate such errors. The necessity to optimize the segmentation methods by minimizing the execution times and controlling the final quality, explains the use of semi-automatic procedures involving several types of data such as, cryosection images, CT, and Magnetic resonance imaging (MRI).

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