PhD Thesis Title: "Integration of Shape Analysis and Knowledge Techniques for the Semantic Annotation of Patient-Specific 3D Data"

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ABSTRACT

In the digital age of medicine, patient-specific 3D anatomical models are expected to be of critical significance in several applications, such as bio-mechanical simulation, virtual surgery, implant design, and computer assisted diagnosis. While there is an agreement on the importance of patient-specific 3D models, there is still a huge gap between the raw patient's data and the 3D models able to digitally represent, and simulate the specificity of each patient.

The shape of anatomical structures is highly important: it is related to function and its deviation from a normality might indicate pathological conditions. Yet, the 3D models used to represent anatomical structures are not suitable to document the variety of attributes and properties that could be useful in medical applications. Also, given the complexity and variability of the shape and shape features, even within healthy population, the methods available to study quantitatively and qualitatively the morphology of anatomical parts on digital models are still far from being satisfactory.

In this thesis, we aim at demonstrating how to properly model patient-specific 3D data so that their anatomical parts can be analyzed and accurately documented at the geometric and semantic level. A tighter integration of geometric analysis and semantic modelling reduces the semantic gap between patient-specific 3D data and formally represented domain knowledge. To this end, we propose original approaches to part- based annotation of 3D patients' data and to the representation of these semantics in a machine-readable way. The semantic annotation of 3D data also provides a basic approach for sharing and reusing knowledge among clinicians, which represents a possible building block for the next-generation of computer-assisted diagnosis systems.

1. The core research contributions are two complementary ontology-driven part-based annotation methods:

    a. *top-down* – to perform the identification and annotations of anatomical landmarks in patient-specific 3D models by using a 3D annotated template; this technique exploits recent results on statistical shape analysis and mean shape generation for producing the 3D geometry of the template, and proposes a transfer of the annotation from the template to the patient-specific 3D model using registration techniques;
    b. *bottom-up* – to recognize automatically anatomical landmarks by using machine learning techniques based on a rich set of morphological feature vectors;

2. A novel set of feature descriptors, which act at the level of anatomical district and not simply of each single bone. These descriptors can characterize patient-specific 3D models in terms of functional regions (articulation and adjacency of the bones in the anatomical district), and pathological markers (erosion score and erosion map);

3. An ad-hoc Carpus ontology, which is defined to realize the conceptualization of the context at the required level of granularity and exemplify the richness of the annotations that can be associated to geometric models and their subparts;

4. A novel data model for part-based annotations of 3D models, which can be used to share semantically enriched 3D geometries.

The proposed approach has been demonstrated by implementing a prototype SemAnatomy3D for the semantics-driven annotation of 3D patient-specific models and their parts-of-relevance, characterized by anatomical, functional landmarks or pathological markers (e.g. articular and non-articular facets, prominent features, ligament insertion sites, erosion locations).The whole framework is specialized to support the diagnosis of rheumatoid arthritis in the carpal bones, but, in principle can support similar tasks in other clinical applications. The system has been designed and developed within the framework of different international and national research projects. Finally, a validation study has been performed to evaluate our proposal by engaging several experts with distinct medical backgrounds where SemAnatomy3D appears as a useful tool for clinical data analysis and opens new ways to support clinical diagnosis.

References to publications that relate specifically to the dissertation:

1. **Banerjee, I.,** Patané, G., & Spagnuolo, M. (2017). Combination of visual and symbolic knowledge: A survey in anatomy. Computers in Biology and Medicine, 80, 148-157.
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3. **Banerjee, I.,** Agibetov, A., Catalano, C. E., Patané, G., & Spagnuolo, M. (2016). Semantics-driven annotation of patient-specific 3D data: a step to assist diagnosis and treatment of rheumatoid arthritis. The Visual Computer, 32(10), 1337-1349.
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5. **Banerjee, I.**, Laga, H., Patanè, G., Kurtek, S., Srivastava, A., & Spagnuolo, M. (2015, September). Generation of 3D canonical anatomical models: an experience on carpal bones. In International Conference on Image Analysis and Processing (pp. 167-174). Springer International Publishing.
6. **Banerjee, I.,** Catalano, C. E., Robbiano, F., & Spagnuolo, M. (2014). Accessing and representing knowledge in the medical field: visual and lexical modalities. In 3D Multiscale Physiological Human (pp. 297-316). Springer London.