A Physics Based Method for Combining Multiple Anatomy Models with Application to Medical Simulation

Yanong ZHU [a], Derek MAGEE [a,1], Rishya RATNALINGAM [b] and David KESSEL [c]
[a] *School of Computing, University of Leeds, UK*
[b] *Mid Yorkshire Hospitals NHS Trust, Wakefield, UK*
[c] *Leeds Teaching Hospitals NHS Trust, Leeds, UK*

Abstract. We present a physics based approach to the construction of anatomy models by combining components from different sources; different image modalities, protocols, and patients. Given an initial anatomy, a mass-spring model is generated which mimics the physical properties of the solid anatomy components. Thishelps maintain valid spatial relationships between the components, as well as the validity of their shapes. Combination can be either replacing/modifying an existing component, or inserting a new component. The external forces that deform the model components to fit the new shape are estimated from Gradient Vector Flow and Distance Transform maps. We demonstrate the applicability and validity of the described approach in the area of medical simulation, by showing the processes of non-rigid surface alignment, component replacement, and component insertion.

Keywords. Virtual anatomy, medical simulation, physics based

Introduction

This paper addresses the issue of efficiently generating anatomical models suitable for use in computer based simulation of medical procedures. When learning medical procedures it is desirable to have a wide range of anatomies/pathologies (or “cases”) on which to practice. The generation of such models usually requires data segmentation which is an interactive process combining semi-automatic methods and manual input (e.g. in [1]). It is desirable to minimise this effort by using data which is readily segmented. This may involve combining information from different imaging modalities, imaging sequences and even different patients. The main difficulties with this approach are different patient positioning and scan resolution and variations in the geometry of anatomical structures/organs. We present a mass-spring model based method that is capable of combining multiple anatomical components derived from different imaging datasets, while preserving the characteristic spatial relations between the anatomical structures.

1. Method

An overview of the approach is given in Figure 1. The source of the anatomy model is a volumetric segmentation that contains the labelling of the anatomy components of

[1]Corresponding Author: School of Computing, University of Leeds, UK. E-mail: drm@comp.leeds.ac.uk

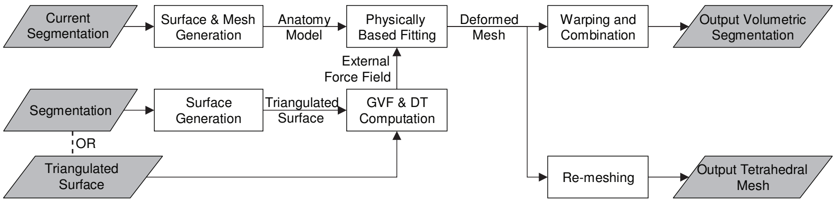
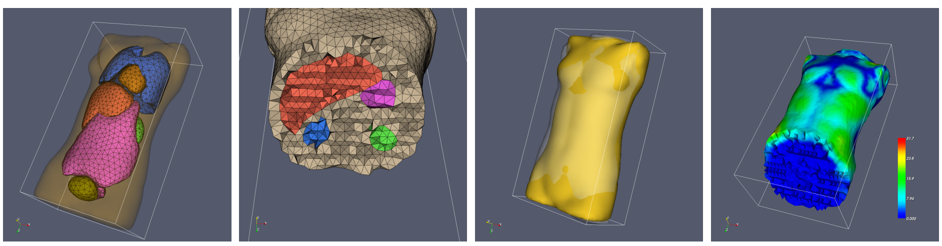


Figure 1. Overview of the proposed method.

interest. We first compute a triangulated surface of each component using the triangulation approach described in [2]. To construct a tetrahedral mesh that contains relevant anatomical components, the Delaunay triangulation algorithm is first applied to a set of uniformly distributed grid points to generate an initial tetrahedral mesh, a relaxation step is then performed to improve the regularity of the tetrahedrons near to the component surfaces. This mesh is the basis of the mass-spring system that regulates the spatial relationship between adjacent components. The fitting procedure, which deforms the mesh to fit the new component, is realised by applying external forces to the mass-spring system. The external force at each surface node of the existing components is computed as the product of Gradient Vector Flow [3] and Distance Transforms [4] at the node, with reference to the new component. After the system is solved, the deformed mesh is ready for the existing component to be replaced by the new instance, or for the new component to be inserted. The resultant model can be in the form of a tetrahedral mesh, or a volumetric segmentation, produced by warping the source volume using the deformed mesh.

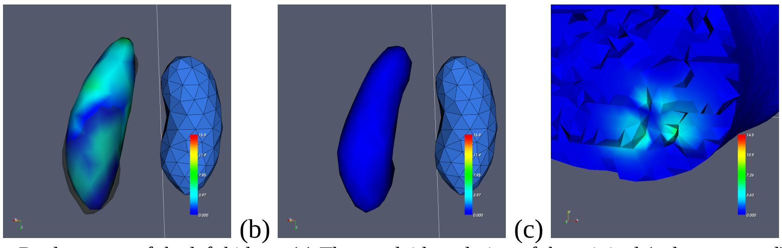
2. Examples of Application

We present three application examples of the described methodology to the anatomy model constructed from a CT volumetric image of a young female. The image was manually segmented by an expert radiologist. The major components in this model and the tetrahedral meshes generated by the meshing technique are shown in Figure 2 (a-b). The first example, presented in Figure 2 (c-d), is surface alignment using the physics based fitting method. The aim is to align the virtual patient body to a different surface. Figure 3 illustrates the process of replacing the left kidney with a new kidney extracted from a kidney-specific CT scan. In the third example we show the process of inserting a new right kidney extracted from the same CT scan (Figure 4).



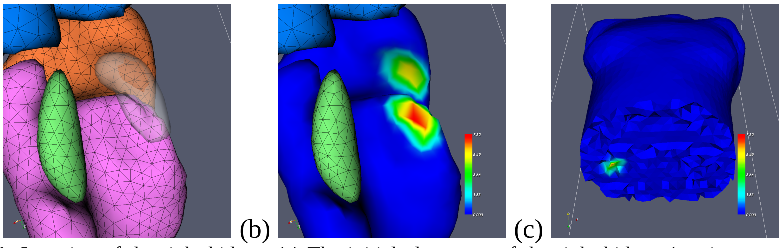
(a) (b) (c) (d)

Figure 2. The anatomical model and the alignment of the virtual body surface to the (partial) surface of a physical mannequin. (a) The phantom components; the surface is made semi-transparent for better display; (b) Clipped tetrahedral mesh; (c) The overlaid rendering of the phantom surface (amber) and the mannequin surface (transparent) (RMS = 10.78mm); (d) Displacement of the internal vertices after fitting (RMS = 0.0mm).



(a) (b) (c)

Figure 3. Replacement of the left kidney. (a) The overlaid rendering of the original (colour mapped) and new left kidney (semi-transparent). For a clearer visual inspection, other components are not shown. The colour map represents the distance between the kidneys before fitting (RMS = 4.32mm). (b) The distance after fitting (RMS = 0.0mm); (c) Clipped mesh showing the displacement of the surroundings caused by the fitting.



(a) (b) (c)

Figure 4. Insertion of the right kidney. (a) The initial placement of the right kidney (semi-transparent); the kidney overlaps with the liver (orange) and the bowel (pink); (b) Displacement of the liver and the bowel; (d) Clipped mesh showing the deformation caused by the insertion.

3. Discussion

A key aspect in the described methodology is the use of the mass-spring system. As a physics-based technique, it can be used to alter the shape of the anatomic components, given that an external force field is well defined; in the meantime it can preserve the integrity of the anatomic model components, and their spatial relationships, by mimicking the physical elastic properties of the solid geometries. These enable us, as shown in the presented applications, to perform various tasks for the construction of anatomy models, such as non-rigid surface alignment, component replacement, and component insertion. More importantly, the proposed approach provides an efficient solution to the construction of virtual anatomies by avoiding complete re-segmentation of the data; and it may be the only option in many cases as full body / abdominal scans are not routine practice. In addition, this methodology is potentially applicable to other areas that involve the modelling of solid anatomical structures. It can be applied to accomplish non-rigid registration of the image data for various purposes (e.g. atlas computation). Another possible application is to simulate the effects of tumour growth on surrounding structures, which may be useful for surgery simulation tasks.

References

[1] Y. Zhu, et al, A training system for ultrasound-guided needle insertion procedures, *Proc. of MICCAI* Part I, (2007) 566-574

[2] J. Boissonnat, et al, Provably good sampling and meshing of surfaces, *Graphical Models* **67**, (2005) 405-451

[3] C. Xu, et al, Snakes, shapes, and gradient vector flow, *IEEE Trans. on Image Processing* **7(3)**, (1998) 359-369

[4] C. Maurer, et al, A linear time algorithm for computing exact Euclidean distance transforms of binary images in arbitrary dimensions, *IEEE Trans. on PAMI* **25(2)**, (2003) 265-270