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► To cite this version:

Maud Marchal, Emmanuel Promayon, Jocelyne Troccaz. A Discrete Soft Tissue Model for Complex Anatomical Environment Simulations. *Medicine Meets Virtual Reality 14*, Jan 2006, Long Beach, California, United States. pp.364-366. hal-00206155

HAL Id: hal-00206155

<https://hal.science/hal-00206155>

Submitted on 16 Jan 2008

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A Discrete Soft Tissue Model for Complex Anatomical Environment Simulations

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Abstract. Among the current challenges in human soft tissue modeling for medical purposes, the ability to model complex anatomical structures, their interactions and to accurately simulate them with physical realism are in the forefront of research. This paper describes a discrete soft tissue model which is geared toward solving these challenges. In this model, objects can be described as volumetric or surfacic sets of nodes depending on the level of precision required. Nodes have their own physical properties and a definition of their neighborhood. All these objects are submitted both to internal cohesive forces and to external attractive or interaction forces with other objects. Volume preservation is insured by a constraint. The model is applied to the simulation of the prostate and its surrounding organs.

Keywords. Discrete model, soft tissue modeling, prostate, complex anatomical environments

1. Introduction

Many algorithms have been proposed for interactively modeling deformable objects such as human soft tissues. However very few have attempted to simulate complex organ interactions. Among the existent soft tissue modeling methods, two main approaches are taken[1]: the biomechanical approach, an accurate but often considered as a slow method and the computational discrete approach, a relatively fast method which main drawbacks are instability, bad physical realism and non-preservation of the volume. For both approaches, there are few examples of the integration of multiple dynamic interactions between soft organs and their environment. In this paper, a discrete soft tissue model is presented. Its originality is to integrate interactions between a given soft organ and the surrounding organs. After a brief description of the model, comparisons with other soft tissue modeling methods are proposed in order to validate the correctness and performances of our model.

2. Model Description

The proposed model is a volumetric evolution of a surfacic model developed in [2]. The components of the model are all derived from a main basis: a set of nodes. A model is de-

scribed using the Physical Model Language (PML) [3]. Each node description contains a list of its neighbouring nodes and different properties depending on the type of component it belongs to (rigid to model skeleton, deformable to model soft tissues and active deformable to model muscles). Our approach allows to define objects not only with nodes on the surface but also with interior nodes. A new feature of the model allows the user to choose to model each component either with a surfacic description (for example a cavity like a bladder) or a volumetric description (a prostate for example). Components can then be easily stitched together: connections between nodes are defined directly in the neighborhood.

To generate displacements and deformations, forces are applied on the different parts of the model. Three kinds of forces can be used: force fields (e.g. gravitation force), locally applied forces (e.g. forces generated by the user or instruments) and local shape memory forces to model deformable properties. The latter are used to compute the elasticity property thanks to the introduction of a local shape memory on each node of the elastic component. Constraints are added to forces in order to model complex behaviours and to maintain some conditions like non-penetrating volume. Incompressibility is achieved through a constraint for surfacic and volumetric component by controlling the surface. To solve the system dynamics, the forces on each node are summed and the equations of motion are integrated taking into account constraints. Contrary to with classical mass-spring models, our model can insure strict volume preservation. It also presents a better stability, as shown in [2]. The next paragraph presents the first comparaisons of physical realism with other soft tissue modeling methods.

3. Validation

First, the model has been validated by comparing it with Finite Element Method (FEM) taken as a "gold standard" of soft tissue modeling. The Truth cube data [4] have been used as first validation of the physical realism of the model (see Figure 1). With these data, we have been able to compare real data with both our model and FEM. The results of the two approaches are very similar. Differences between real data and FEM in one side and our model in the other side are both less than 0.2 mm for 5% compression for example (mean real displacements of 2.64mm) (see [5] for more details).

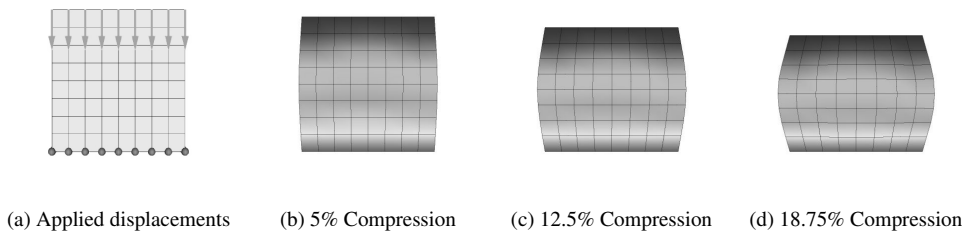


Figure 1. Truth cube Experiments: a compression is applied on the top nodes, bottom nodes are constrained to a null displacement

The second stage of the validation deals with the simulation of endorectal echographic probe influence on prostate shape in function of bladder filling (see Figure 2.a for

prostate anatomy and your model). Organ shapes are simplified but proportional scales are respected. Prostate has a volumetric description while bladder is represented with surface nodes. Bladder and prostate are stitched together with a limited number of nodes and 12 top nodes of the bladder are fixed for each simulation. An imposed displacement is applied upward inside the rectum, resulting in a compression force that deforms the prostate. Prostate and bladder are both incompressible. Different bladder fillings have been experimented (see Figure 2.b). A mean prostate nodes displacement of respectively 4.52 mm, 4.40 mm and 4.37 mm has been observed for a bladder reference volume of V_0 , $2.7 V_0$ and $5 V_0$ (imposed displacement by the probe was 5 mm). This predicts a linear damping of the prostate deformation relatively to bladder volume decrease.

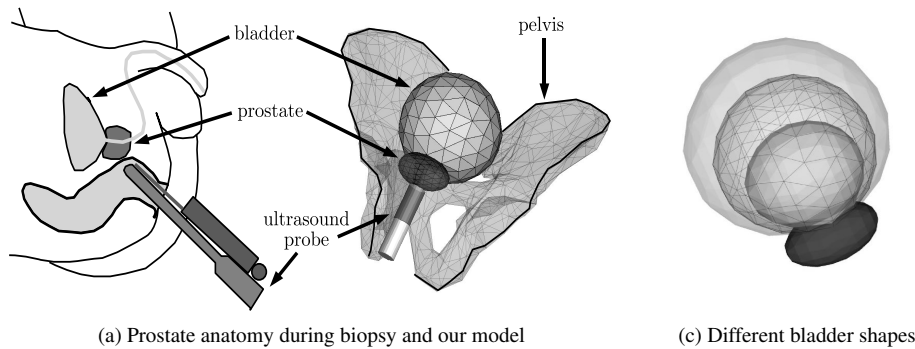


Figure 2. Model of the prostate and different bladder fillings

4. Discussion and Conclusion

In this paper, a new approach to soft tissue modeling well-suited to model interactions between organs has been proposed. The presented model allows to show that interacting organs can be simply defined. Our next work is to incorporate the interactions with instruments and to further validate the model with experimental data.

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