Virtual Open Source environment for training and Simulation of Laparoscopic Surgery

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Abstract. *In the Medical area the use of technological tools for the training process of surgical procedures is an attractive solution, free of risks and implications. In this work the preliminary results of the development of an interactive virtual environment for medical training are exposed. This is developed in the context of an open source simulator of laparoscopic surgery. The geometrical and physical modeling of the anatomical structures or organs involved in surgical procedures are the main focus of this work. Medical images were used to obtain the real anatomical geometries and the Spring-Mass model was applied with a skeleton structure for modeling the mechanical behavior of the soft-tissues. The experimental results for a pancreas are exposed.*

1. Introduction

The Laparoscopic surgery is a technique of Minimally Invasive Surgery, based in performing the surgical procedure by using specialized instruments and a laparoscope video camera inserted through small incisions in the abdominal wall. In this case, the surgeon must guide his actions by relying in the monitor video image, having difficulties by the limited visualization, the loose of depth perception in a 2D video image, a reduced motion range and a limited force feedback.

There are a few training methods for laparoscopic surgery, such as training on cadavers, animals, trainer box, virtual simulators and even on patients, having different ethical and legal implications. The virtual simulator represents a method free of implications, and its effectiveness as a teaching tool has been previously validated by several studies [Schijven and Jakimowicz 2003], [Issenberg et al. 2005], [Palter and Grantcharov 2010]. The idea of this project is to provide a laparoscopic surgery virtual simulator in an open source approach, by releasing the software, manufacturing drawings and electronic circuit designs of the project in a freely and cooperative way. In a first stage, a prototype of the device was developed and exposed in a previous work [Moreno et al. 2012]. In this work, the development progress of the virtual environment is the main focus, including the geometry acquisition from medical images, the graphic structure and the mechanical modeling to simulate the behavior of the soft-tissue involved in the surgical procedures.

2. Anatomically Realistic Geometry

The anatomical geometries are complex surfaces and their acquisition is really important for the simulation process of the surgical procedures that will be included in the virtual environment. The open source software InVesalius [Moraes et al. 2011] was used for this purpose, which acquire the desired geometry from medical images, such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT), by using the marching cubes algorithm to generate triangular meshes. Then different graphical tools can be used to process these models. Using this process, a pancreas geometry was acquired. The result was a mesh of 8,789 vertexes and 17,578 faces, meaning a high computational cost. A simplified mesh is required in order to achieve a better interactive response [Cotin et al. 1999], [Zhang et al. 2006]. Using graphical simplification tools, a derived mesh with 446 vertexes and 548 faces was obtained and then its graphical quality was improved applying visual filters based on a smoothing algorithm. The results are shown in **Figure 1**.

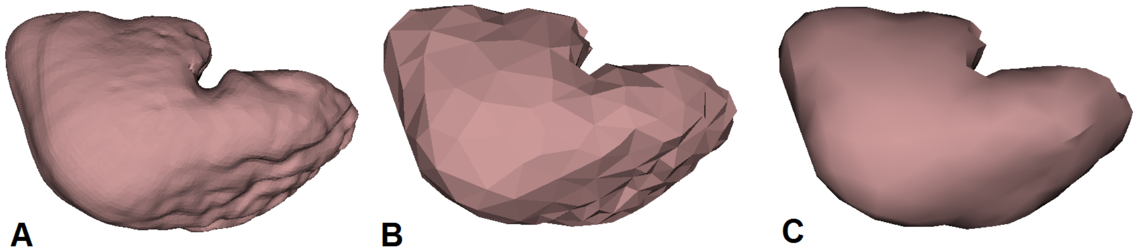

Figure 1. Pancreas mesh A) From InVesalius, B) Simplified , C) Final appearance

3. Physical modeling

The selection of a proper deformation model is crucial for the development of this kind of interactive devices, searching for a balance between surgical realism, real-time graphical feedback and computational cost in the simulation process [Delingette et al. 1999]. For this applications, different models have been proposed, among the most important are based on the Spring-Mass model and Finite Element Method (FEM) with different hybrid variations [Delingette et al. 1999], [Schwartz et al. 2005], [Zhang et al. 2006], [Kera et al. 2011]. These methods were studied, and although FEM has a great accuracy also require a high level of implementation and computational processing, and could not be able to work properly in every computer where the system were attempted to be executed. With this in mind, the Spring-Mass model was used with a skeleton structure to represent the internal volume deformation of the pancreas [Zhang et al. 2006], [Kera et al. 2011].

3.1. Skeleton structure

In this case, the skeleton was used to represent the internal volumetric deformation caused by the superficial displacement of points. This skeleton was formed using a mesh of control points obtained from the simplification of the superficial topology with dimensional proportion and correlated to the center of the geometry. Each vertex in the pancreas geometric model is linked with the four nearest vertex in the mesh of control points [Zhang et al. 2006], forming the skeleton as shown in **Figure 2**. The deformation model is applied to the structure conformed by the superficial and skeleton meshes.

3.2. Deformation model

The Spring-Mass model represents the object as a set of mass points linked by springs between them. With this perception it is possible to calculate the elastic restoring force

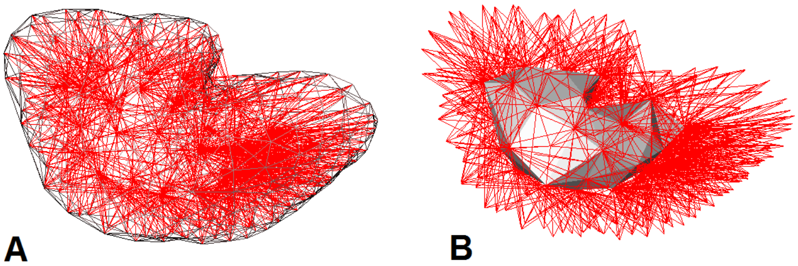

Figure 2. A) Geometric model with Skeleton, B) Internal mesh of control points

F_i that the displacement of a point P_i applies on a point P_j considering his neighbors points $N(P_i)$ using the constitutive equations of the system based on the Hook's Law [Delingette et al. 1999], [Zhang et al. 2006], [Kera et al. 2011]

$$F_i = \sum_{j \in N(P_i)} k_{ij}(\| P_i P_j \| - l^0_{i\,j}) \frac{P_i P_j}{\| P_i P_j \|}$$

where k_{ij} is the stiffness coefficient of the spring that connects the point P_i and P_j, and $l^0_{i\,j}$ is the original length of the spring in rest position. By knowing the force applied to the point P_j caused by the displacement of the point P_i, it is possible to calculate the displacement of the point P_j using a second order differential equation based on the Newton's motion law

$$m_j \frac{d^2 u}{dt^2} + d_j \frac{du}{dt} + k_{ji} u = F_i$$

where m_j is the mass of the point P_j, the d_j is a damping coefficient and k_{ji} is the stiffness coefficient of the spring. The numerical method used to solve this equation was the Euler's method with a central finite difference [Zhang et al. 2006].

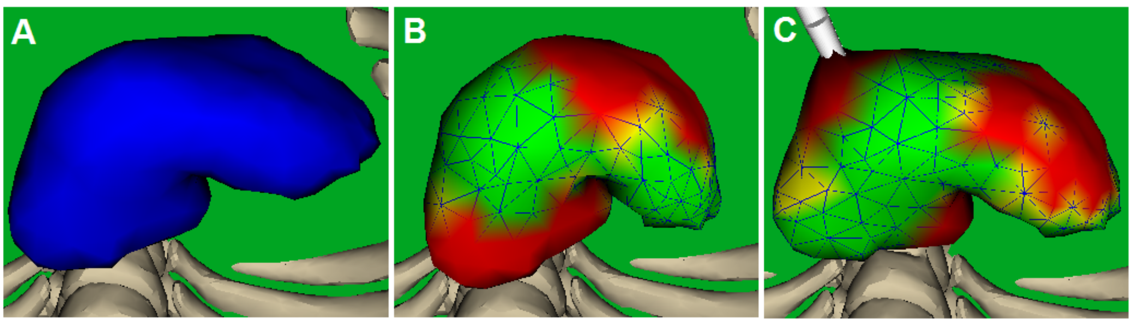

Figure 3. Pancreas mesh A) In rest position B) Under the influence of gravity C) Being deformed by user interaction

4. Experiments

The experiments were performed using this deformation model and implementing with the geometrical model, the fitting parameters were established and a set of points were defined as a fixed constraint, the model was tested with gravity and user interactions as shown in **Figure 3**. These tests showed that the model tends to be stable in the deformation range experimented by the tissues in a real life surgery, and the model's computational cost allows its use for interactive applications.

5. Conclusions

The Spring-Mass model with skeleton structure has shown promising results, but the parameters have to be defined for each material using its mechanicals properties. For future works are being considered 1) the use of a different data structure required for the collision detection, such as KD-Tree; 2) the implementation of other physical models to describe the soft-tissue behavior and 3) the application of other numerical methods to solve the differential equation. The integration of the system with the hardware of the device's prototype will be tested.

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