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Modeling Interactions with a Computer Representation of the Upper Gastrointestinal System

Gastélum Alfonso, Mosso José L, and Márquez Jorge

Abstract— **Our goal is to simulate interactions with a computer model of the esophagus and the stomach, built from the *Visible Human* database, and reported in previous works. The optical distortion of the endoscope was simulated during navigation allowing the user a quantitative assessment of distortion when he measures an injury. Another improvement to our model is the inclusion of abnormal anatomy, from two types, the first one is related to the color features of the disease and the second is a direct modification in the triangle structure of the mesh, with the goal to simulate blisters and injures in the model. The esophagus in its natural state presents radial collapsing, which was simulated using finite element methods. To this collapsed state we superposed the interaction of the triangle mesh with a model of the air pressure against the walls. The collapsed state allows to train the user in the insertion of the endoscope and to assess the effects of friction between the walls and the instrument.**

I. Introduction

COMPUTER training in endoscopical procedures allows the specialist to interact with a virtual model and provides different points of view of the anatomical area of interest. Such enriched navigation permits the specialist to have a better understanding of the whole volume. To complete a computational training system from our gastrointestinal model, reported in [1], we developed a navigation environment that permits a user to explore the model and to be trained on detection of anomalies.

Computer models for endoscopy training have already been reported [2]; our approach is to give the user the possibility of training in two areas that these models do not provide: the optical distortion and the insufflation process.

The goal of the present work is to simulate interactions with a computer model of the esophagus and the stomach, built from the color anatomical slices of the *Visible Human* database [3]. To simulate interactions with the model, it is first collapsed to obtain a natural state, then navigation was enhanced to allow the user to insufflate into the gastrointestinal track. These and other improvements provide the user with a closer experience to reality when he is training in the computational environment of our system.

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Gastélum Alfonso is with the Center of Applied Science and Technological Development, National Autonomous University of Mexico, P.O. Box 70-186, 04511 México D.F., México (corresponding author to provide phone: +(55)56.22.86.02 ext. 1130; e-mail: valdenar@ gmail.com).
Mosso José L, is with the Clinic Dr. Alberto Pisanty Ovadia, C.P 11870 México D.F., México (corresponding author to provide e-mail: quele01@yahoo.com).
Márquez Jorge is with the Center of Applied Science and Technological Development, National Autonomous University of Mexico, P.O. Box 70-186, 04511 México D.F., México (corresponding author to provide phone: +(55)56.22.86.02 ext. 1130; e-mail: marquez@aleph.cinstrum.unam.mx).

II. PROCEDURE

Since our model is built to serve as a training system, the navigation must provide the closest possible realistic behavior, hence, we introduced a optical barrel distortion [5,6] that allows to experiment the point of view of a real endoscope. We also simulated abnormal anatomies and the deformation of the esophagus due to the presence of air.

There are two main problems in this stage: the first is the computational burden of real-time deformation of the mesh, the second is related to the physical behavior of fluids and its representation in a computational environment. A problem arises when the process of air insufflation is introduced to our model: the increased time in rendering and a slow feedback interaction. To solve this we first divided the process of navigation and interaction into pre-calculated and real-time computed features, the first one are modifications to the color or the structure of the triangle mesh; these modifications are pre-calculated since their characteristics will remain the same during the time the user interacts with the model, the second one consists of mesh modifications during navigation, depending on user interaction, and cannot be pre-calculated. The real-time calculations need to be done using approximated numerical solutions, maintaining a fast interactive environment. The first step is to classify all mesh modifiers that do not need to be made in real time: these are color modifications and solid structure modifications.

The color modifications are introduced as a representation of diseases produced by the constant exposure of the esophagus to the peptic acid. Such diseases can be considered to be in the initial stages before structure alteration, examples of such diseases are: Gastroesophageal Reflux Disease (GERD), reflux esophagitis, Barret disease and some ulcers.

In Fig. 1 is shown the effect of the peptic acid in the color of the model (shown here in gray levels), depending on the type of disease and its severity; the intensity, hue and extension will change, whereas position and severity vary each time the model is run.

Different colors for the model were obtained from video-endoscopies, this was needed because the original color was obtained from the post-mortem *VHP* database. To achieve color segmentation from a video-endoscopy we divided the video into frames and used the lens distortion equations to obtain the center of each image, this gives an approximated

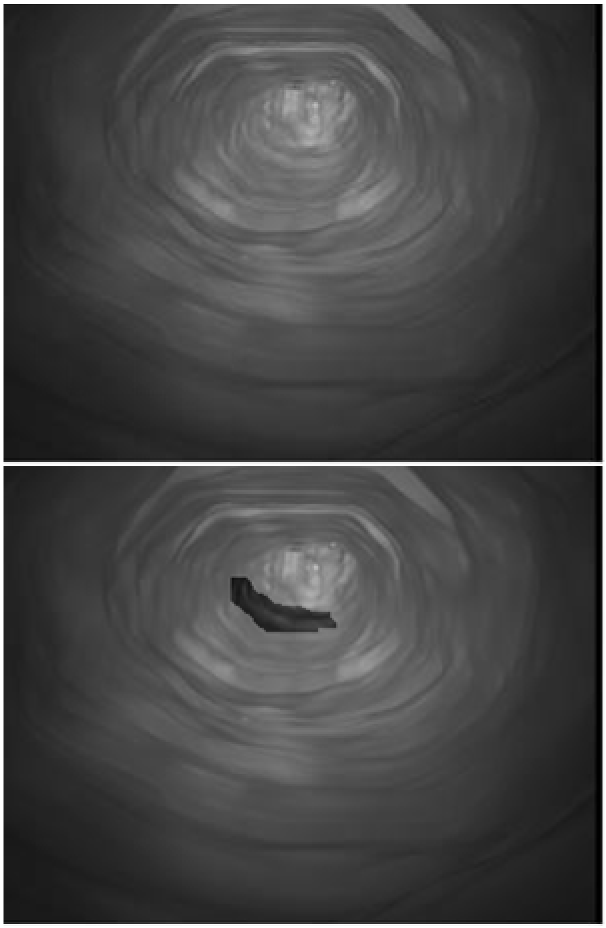

Fig. 1. Effect of the peptic acid a) Normal tone of the model b) Change in tone in the esophagus due to the presents of acid.

pixel map of the real esophagus. After obtaining a more realistic color of a healthy esophagus we analyzed different video-endoscopies with the aid of a specialist to obtain the color pattern associated with different diseases.

The solid structure modifications are changes in the esophagus produced by extended damage. In our model it required the building of new triangular meshes. In Fig. 2 we show a rendering corresponding to a high degree of varices.

The second kind of modifications are calculated in real time, depending on the user decisions and the position of the lens of the endoscope, so they required an algorithm preventing slow feedback; it also integrates the optical distortion and the simulation of the insufflations process during navigation.

A barrel geometrical distortion is present in common endoscopes. To obtain the distortion parameters in a real endoscopical lens we used a grid image viewed trough the lens. The two sets of points with and without lens are related by the following inverse transformation in implicit form [4]:

$$\begin{pmatrix} x_d \\ y_d \end{pmatrix}_{(j+1)} = \begin{pmatrix} x_d \\ y_d \end{pmatrix}_{(j)} - \left(\frac{\partial g((x_d, y_d)_{(j)})}{\partial((x_d, y_d)_{(j)})} \right)^{-1} \left(g(x_d, y_d)_{(j)} - \begin{pmatrix} x_u \\ y_u \end{pmatrix} \right) \quad (1)$$

The result of the iterated process is shown in Fig. 3. The simulation of distortion is justified when a measurement is

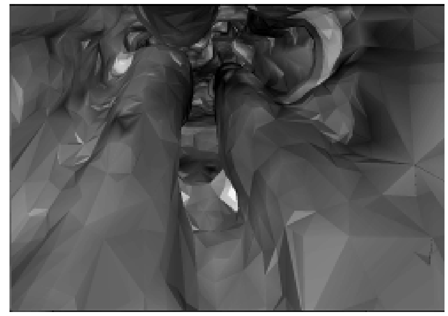

Fig. 2. Varices produced in the esophagus.

made. This modification is only applied during rendering where the original position of the vertex is not changed, and only calculated on visible features of the model.

Thereafter we introduced the simulation of the insufflation

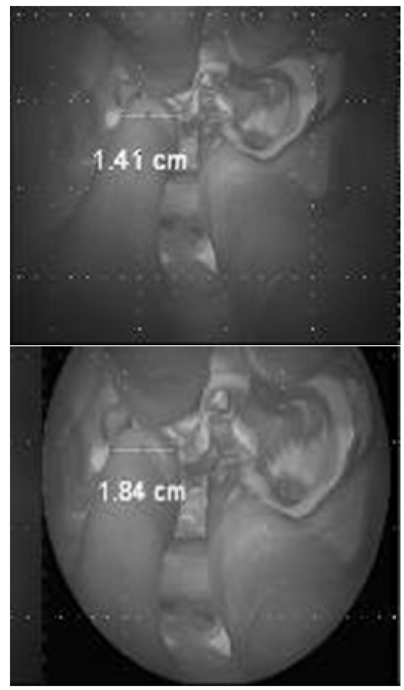

Fig. 3. Result in the measure of the varices due to the optical distortion.

process, since the gastrointestinal system is initially collapsed and, to improve the navigation and visibility, the endoscopist must introduce air in order to expand the esophagus and stomach.

To this end we implemented the *Smoothed Particle Hydrodynamics* (SPH) fluid technique [7], using the properties of fluid dynamics to build an approximate behavior of the air pressure over soft tissue. Particle dynamics allows calculation of position and velocity of a set of particles and also to interpolate the properties of the air pressure in a given region, as well as the interaction with the boundaries.

Fluid dynamics is the study of fluid motion in response to forces such as gravity and pressure [8]. The equations of motion for a compressible fluid are:

$$\frac{d\rho}{dt} = -\rho\nabla \bullet v \qquad \frac{dv}{dt} = -\frac{1}{\rho}\nabla P \qquad \frac{du}{dt} = -\left(\frac{P}{\rho}\right)\nabla \bullet v \quad (2)$$

Where ρ, v, P and u represent density, velocity, pressure and energy, respectively. The idea behind SPH is the determination of fluid characteristics by interpolating from a set of non-ordered points representing the particles. The insufflated air, modeled as a fluid, is partitioned into N regions with local densities defined by:

$$\rho_i = \sum_j m_j W_{ij} \quad (3)$$

Where m_j is the mass of the particle j, and the sum is over all particles. The interpolation is performed using a smoothing kernel W which is a weighted sum over particles within an area defined by a smoothing length h.

There are various forms of W, however the most advantageous (3) is:

$$W(r,h) = \frac{1}{\pi h^3}\begin{cases} 1 + \frac{3}{2}q^2 + \frac{3}{4}q^3 & \text{if } 0 \le q \le 1 \\ \frac{1}{4}(2-q)^3 & \text{if } 1 \le q \le 2 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Where $q = \frac{r}{h}$ and r is the average distance between particles.

The result of applying this equation in order to simulate the process of insufflations is shown in Fig. 4.

To simulate the wall-particle interaction the calculations of the pressure force of the particle system on the walls of the gastrointestinal system were obtained with the aid of finite-element, mass-spring calculations.

III. CONCLUSIONS

In order to obtain a computational training system for the gastrointestinal model that can be navigated in real time, we required an optimal combination of methods to simulate each of the behaviors and properties added so far. The first improvement was to pre-calculate everything that remains static during the navigation. The final model can be navigated with a high degree of interaction, since our rendering procedure employs a method that provided a discrete solution close to reality, and at the same time, fast enough to maintain a real-time feedback. In the case of optical distortion we modified the original position of the pixel on the screen into the corresponding distorted position; the distortion process is accelerated by pre-calculating, for each pixel, its final distorted position since the screen always maintains the same proportion. For the air dynamics we used ***Smoothed Particle Hydrodynamics*** (SPH), achieving a realistic time responce for user interactions with the model. Finally, when the process of insufflation is calculated, the walls of the esophagus expand accordingly.

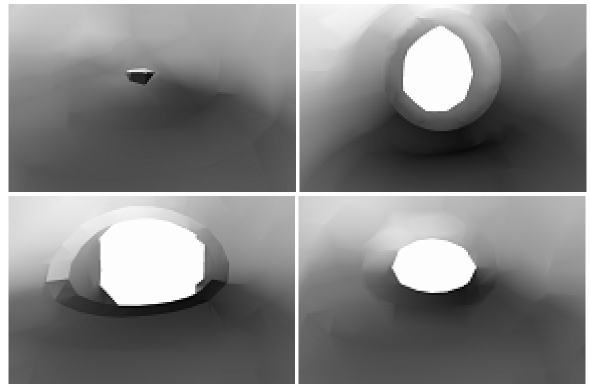

Fig. 4. A set of frames representing the insufflations process.

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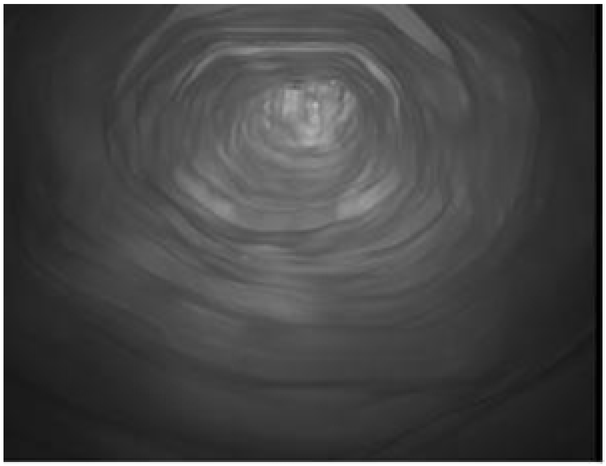

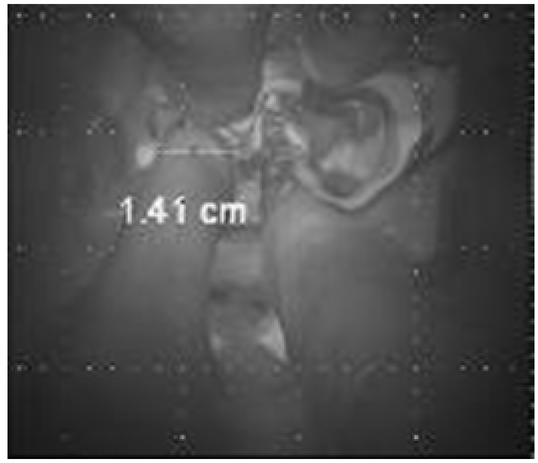
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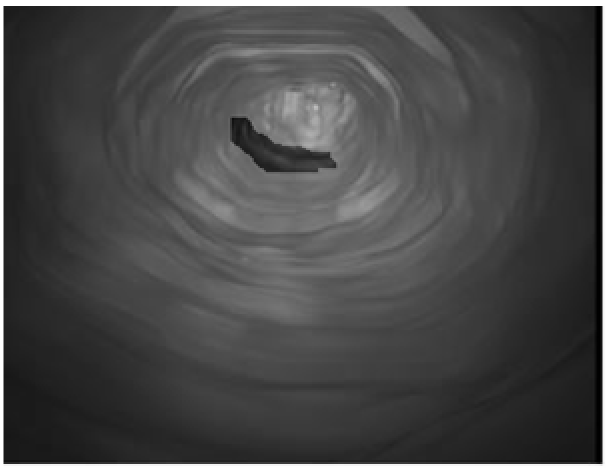

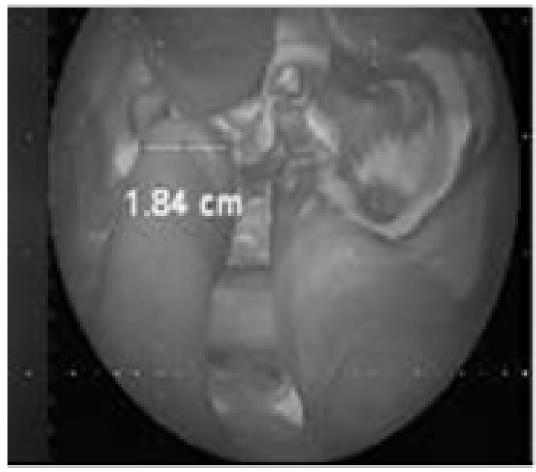
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