PRASAD: An Augmented Reality based Non-invasive Pre-operative Visualization Framework for Lungs

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Abstract

This paper presents a pre-operative anatomical visualization framework, PRASAD (Physically Realistic Adaptive and Scalable Anatomical Deformation system), which combines a bio-mathematical representation of deformable lungs with real-time deformation and stereoscopic visualization technology. This framework provides a visualization of a dynamic patient-specific deformation of synthetic 3D anatomical models, that physicians can view from different viewpoints in a stereoscopic augmented reality environment for efficient diagnosis.

1. Introduction

Creating a visualization of patient-specific anatomical models that displays physically and physiologically realistic dynamic deformations constitutes a significant contribution to medical training and teaching, and may also provide aids to diagnosis in clinical settings.

2. Related Work

2.1 Pulmonary Preoperative Assessment

Surgery simulation has found a place in medical training centers as a means of allowing surgeons to visualize and rehearse surgical procedures in a safe and realistic environment.[1]

Preoperative assessment protocols usually consist of a decision tree design where imaging techniques along with physiology measures are used to predict patient risk for developing pulmonary complications.[2] Of the assessment battery, pulmonary function has been the most studied. These techniques do not combine anatomical and physiological measures to give a complete pulmonary assessment. An anatomically correct 3D computer generated lung model that incorporates patient specific data with physiological measures of pressure-volume changes could bridge this gap.

2.2 Physiological Considerations for Lung Deformations

First, the P-V curve obtained from physiology is used as a driver to the deformable model. Given a P-V curve, the physiology of alveoli distribution is used to specify the local shape of deformation. Specifically, in the normal at rest individual in the upright position, there is a natural intra-pleural pressure gradient from the upper lung region to the lower. The negative intra-pleural pressure at the apex of the lung is normally greater than at the base.[3] Thus the compliance of the alveoli in the upper lung region is normally less than the compliance of the alveoli in the lower lung regions in a normal person in the upright position.

3 Real-time Deformable Models for 3D Augmented Environments

The main objective of the approach developed is to visualize real-time lung physiology-based deformations. We shall provide in section 4.1 the functional architecture of the framework. In section 4.2, we detail the approach to elastic lung deformations. In section 4.3, we discuss the bio-mathematical driver. In section 4.4, we discuss the hardware implementation, and the visualization system is provided in section 4.5.

4. PRASAD implementation for Lungs

4.1 Functional Architecture

A detailed functional diagram of the software implementation is given in fig 1. The implementation is done using C++ in a Linux operating system. We consider two different model formats. A knowledge-base module decides the initial assignment for each node based on the bio-mathematical model of lungs.[4] The 3D Model Deformer module, updates the position

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of every node based on the required change in volume, which is calculated by the bio-mathematical driver. Stereoscopic ARC display module renders the 3D deformed model in real-time.

4.2 Elastic Lung Deformations

Elastic lung deformations are caused by an increase or a decrease in volume due to internal forces. In our approach, we have pre-computed the strain at each surface node for a given minimum force (pressure/area) and have used the strain for scaling the model. The strain has a direction and a magnitude component. A detailed discussion of the method developed is given in [4].

4.3 Bio-Mathematical Driver

In order to increase or decrease the volume of lungs in a physiologically accurate manner, we introduce the bio-mathematical driver, which implements the functions similar to the control of breathing by the nervous system. A detailed description is given in [5].

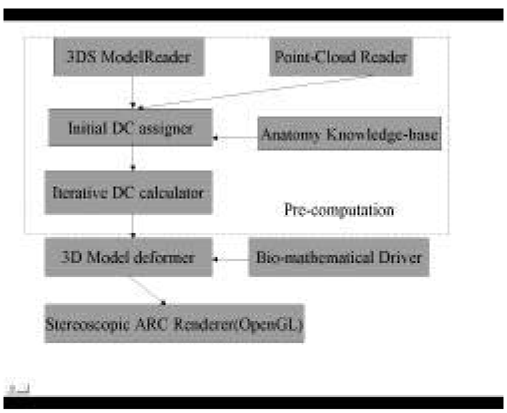

Fig 1. Functional Architecture of PRASAD

4.4 Hardware Rendering

For real-time simulation of the breathing process using a high-density polygonal model of the lungs, we implemented the algorithm in programmable NVIDIA GeForce 4 using CG2.0. All the vertices of the lungs model were first loaded into the AGP memory.

4.5 ARC System

The initial implementation of PRASAD utilizes a quasi-circular (4.57 m/15 ft. diameter) ARC display as shown in fig. 2, designed as part of RAVES project, a multi-modal Augmented Reality System with 3D visual, 3D audio and haptic capabilities. The display consists of a curved wall of retroreflective material, a head-mounted projective display (HMPD), and a Linux-based PC.

In the ARC display, the optics of the HMPD project a left and right image into the augmented VE using a 50/50 beam splitter to reflect light off the retroreflective material. Because the retroreflective material reflects the light in the opposite direction of its incidence, stereo images are returned to the eyes of the user.[6]

5 Conclusion

The deformable lung visualization has been implemented in the ARC system. The future work involves modeling pathologies accurately and introducing synchronization with the deformable human body.

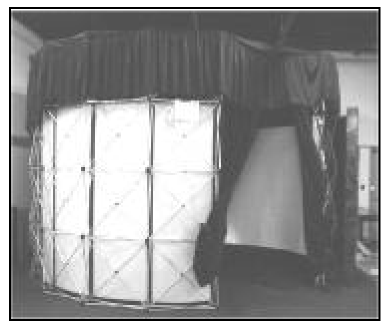

Fig 2. ARC display

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