Analysis of the Pulmonary Vein Ostia using Cardiac 4DCT for Radiosurgical Ablation

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Abstract
A software tool to analyze 4D cardiac CT data sets for planning radiosurgical ablations in the heart is presented. Volume rendering and data processing are performed using a GPU. The user visualizes the data from inside the left atrium and defines the target in 3D using an intuitive user interface. A haptic input device lets the user measure motion at the ostia of the pulmonary veins for radiosurgical treatment planning. This tool has been used effectively for generating radiation treatment plans for animal studies.

Categories and Subject Descriptors: Feature Measurement, Computer Vision, Object Representation, Three-Dimensional Graphics and Realism, Manipulators

1. Introduction

Atrial fibrillation is a disease in the heart characterized by irregular rhythm. The present approach to treating this disease is to create lesions at the pulmonary vein (PV) ostia using RF energy deposited by catheters. Such procedures are highly invasive and commands specialized skills since it involves threading a catheter via the inferior vena cava into the right atrium, performing a trans-septal puncture and locating the ostia of the PVs under fluoroscopy guidance. Creating lesions in the myocardium using high energy external X-ray radiation beams has been recently demonstrated in swine model using the CyberKnife robotic system (Accuray Incorporated, Sunnyvale, California, USA) [SMW*07]. Compared to the present catheter-based approaches, the new method reduces the invasiveness and decreases the treatment time.

2. Background

Radiosurgery has been used in the past to deposit radiation to tumor sites. The target and the surrounding tissues are first imaged using 3D Computed Tomography (CT). The clinician then views the axial CT slices and contours the target area manually. A treatment planning software module analyzes the contours, the CT data and determine a set of 100 or so vectors, all converging on the target area to deposit the desired dose. A control system then directs a 6 DOF robot manipulator holding the 6 MeV X-ray source to a set of points on the aforementioned vectors, aims and fires the beam to deposit radiation at the target. If the target is inside the lungs, the robot manipulator follows the breathing motion while firing the beam. Treatment targets at the pulmonary vein ostia are identified on 4DCT datasets obtained with ECG-gated CTA (10 3D volumes are reconstructed at 10% intervals of the cardiac cycle). Our goal is to develop an intuitive way (a) to define the target areas, i.e. the ostia of the PVs, and (b) to measure the cardiac motion of the ostia, for the purpose of treatment planning

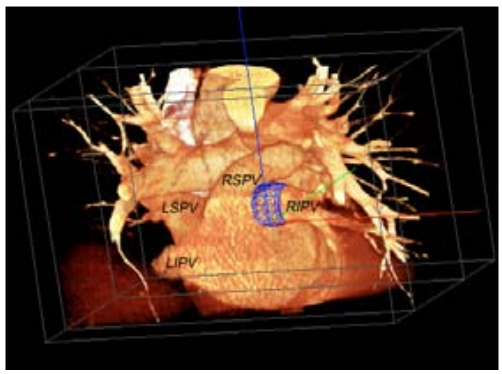

Figure 1: A volume rendering of left/right superior/inferior PVs entering the left atrium and a delineated target, as viewed from outside.

3. Method

Our OpenGL application runs on a Windows XP system using a NVIDIA Quadro FX4600 graphics accelerator. To minimize the 4DCT data transfer times from the CPU memory to the GPU memory, data streaming is used using pixel buffer objects. Volume rendering is performed using 3D texture-based methods on the GPU [EHK*04]. Other types of processing such as filtering are also performed on the GPU to minimize the computational overhead of the CPU.

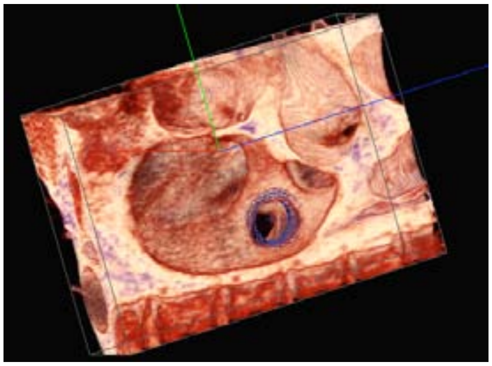

Figure 2: A volume rendering of a PV with the toroidal target defined by the user, as viewed from inside the left atrium.

3.1 Target Delineation

Our application lets the user investigate the target area from multiple angles using two different color maps: (A) highlighting the tissue/blood lumen boundary as viewed from outside the heart, and (B) highlighting the same boundary as viewed from inside the left atrium. The user can then position and orient a toroidal shape at the ostium of a PV (Figures 1 and 2). Following the target delineation, the position, orientation and the shape of the toroid are passed on to the treatment planning module to generate the set of beam vectors for the robot.

3.2 Motion Measurement

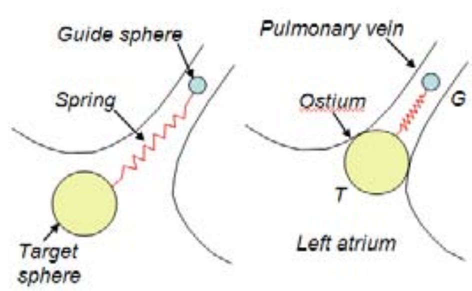

Figure 3: The user drags a smaller guide sphere (G) along the PV, starting from the left atrium. The larger target sphere, T, attached to G via a spring, follows and gets stuck inside the ostium of PV.

The treatment planning module also requires the motion of the target over one cardiac cycle for its beam vector computation. We have developed a tool for tracking the motion. As shown in Figure 3, using a haptic input device (Omega Device by Force Dimension, Switzerland) the user can attach a sphere to the ostium. Force feedback prohibits the user from crossing the blood lumen/tissue border. The force in the spring maintains a tight contact between T and the blood lumen/tissue border. The lumen/tissue border can then be changed by cycling through all the 10 volumes of 4DCT data. G is kept at a stationary point while T is allowed to move in 3D space while keeping the spring tight. The center of T is the measure of the motion of the ostium of the PV over 1 cardiac cycle. Figure 4 shows the G and T spheres placed in a human data set.

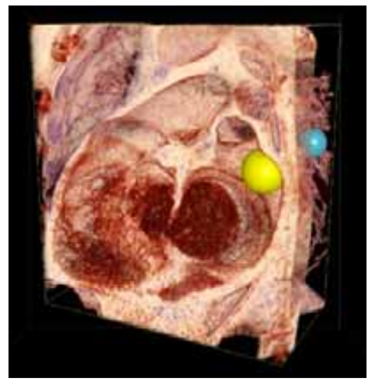

Figure 4: The guide sphere inside a vessel and the target sphere stuck at an ostium in a human CT data set.

4. Discussion

Using the computing power of modern GPUs and the haptic capabilities of a device like the Omega Device, we are able to provide an intuitive tool to the clinicians to visualize 4DCT data sets of the heart of a given patient, delineate complex targets such as the ostia of PVs, and to measure the motion of the target. This cuts down the time the clinician spends in delineating targets for radiosurgical ablations compared to present tools since manually drawing contours corresponding to a toroidal tissue structures in the axial cuts is complicated and time-consuming. Furthermore, by measuring the motion of the target over one cardiac cycle, the treatment planning system can better simulate the dose received by the target.

References

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