An interactive augmented reality 3D visualization system for destroying liver tumor using cryoablation

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Abstract

Cryoablation is one of many local destruction techniques used to remove liver tumors. The procedure is cumbersome and time-consuming if there is no real-time access to intra-operative images as well as navigation information of instruments. In this paper, we propose a software-based solution that addresses issues like interactive, real-time navigation and visualization of cryoprobes, segmented tumor, intra-operative MR images, temperature maps, and isotherm surfaces. The system has an intuitive graphical user interface that provides access to a variety of functionalities. It enables the surgeon to perform the procedure safely, accurately, and rapidly by providing visual decision support mechanism.

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1. Introduction

Minimally invasive therapy has become an active area of research in medicine. Such a therapy is cost-effective for both patients as well as hospitals. One of the main drawbacks in this procedure is the manipulation of the surgical fields through small incisions. This reduces direct-vision and dexterity, and decreases the tactile feedback. Enhanced vision and better navigation may lead to solve some of the problems.

In this paper we focus on developing a novel system for navigation and decision support in local destruction of liver tumors using 3D computer visualization. The system
consists of real-time acquisition of MR images, automatic segmentation of cryolesions, computation of 3D temperature maps, navigation of cryoprobes, and 3D visualization. An interactive user interface enables on-demand request for additional visual information like isotherm surfaces and tumor surface temperature.

2. Materials and methods

A number of different local destruction procedures to hepatic tumor can be found in the literature. Freezing (cryoablation), laser-induced thermotheraphy, radio frequency, and microwave ablation are commonly used procedures [1–3]. We use the CryoHit system (Gail Medical, Israel) where high pressure argon gas is circulated through the cryoprobes to freeze tumor tissue.

The open 0.5-T magnetic resonance imaging (MRI) scanner Signa SP/i (GE Medical Systems, USA) is used as an imaging modality for acquiring both pre- and intra-operative images. Pre-operative image volumes have a size of 256 × 256 × 60 and intra-operative image slices have a size of 256 × 128. Optical tracking device (Flashpoint 5000, Image Guided Technologies, USA) provides location of the cryoprobe in the magnet. The device has light emitting diodes (LED). Three linear infrared video cameras mounted in the magnet provide position of the LEDs in image volume.

A computerized algorithm that uses pre-operative MR image volume is used to derive a virtual cryopath taking into consideration feasible percutaneous access, major hepatic veins, and tumor location. Such a virtual path provides direction for incision of the needle from outside the patient’s body to inside the liver, all the way down to hit the tumor.

A novel interactive 3D visualization software scheme is developed on a hybrid Linux-Silicon Graphics (SGI) platform. The software is divided into two parts, server and client. The server part supports real-time access to imaging devices, tracking devices, and image processing tools. This framework was described in Ref. [4]. We extended the framework by adding a server that provides access to 3D polygonal surfaces of segmented tumor and thermal information.

The client part consists of scene graph, stereo camera settings, and graphical user interface (GUI). The 3D scene consists of 2D MR slices which are presented as texture data on a plane, 3D liver surface, 3D tumor surface, 3D ice ball, 3D isosurfaces, and two different 3D cryoprobes. One probe shows the planned trajectory using pre-operative MR images to hit the tumor. The other probe moves inside the liver in real-time corresponding to the cryoprobe which is being tracked.

GUI implementation is based on Qt package from Troll Tech in Norway. It is a single code base, multi-platform C++ software tool. Scene graph implementation is based Coin package from Systems in Motion, Norway. It is a 3D graphic library with a C++ application programming interface (API) and is based on OpenGL. We use distributed inventor (DIV), a package in Studierstube from the University of Vienna, Austria, to enable a distributed rendering system of a single scene graph on multiple computers. This feature enables us to use a Linux PC as master and a dual-head, 2-CPU, Octane 2 SGI as a slave to render passive stereo. Using perspective camera option in scene graph with correct eye distance produces stereo effect of the scene. Two different types of display systems are
tested for two different purposes. For demonstration of the application for a large audience and in the operation theater, we use two polarized projectors from Barco, Belgium. The passive stereo is projected through circular polarizers on a large screen and is viewed by using corresponding polarized glasses for respective eye addressing. For training purposes, we use head mounted display (HMD) having a resolution of $640 \times 480$ from Vista Medical, USA.

3. Results

A pig was chosen to demonstrate the system. A virtual tumor was inserted. Fig. 2(a) depicts surfaces of the simulated tumor in green and liver in brown. Using pre-operative MR image volumes, a trajectory was derived to hit the target. We placed a virtual, static, yellow colored cryoprobe along the trajectory on the tumor as shown in Fig. 2(b). The opaque surface of the liver is changed to transparent surface. A second virtual dynamic purple colored cryoprobe is also depicted in Fig. 2(b). Both virtual probes were modeled in 3D as a replica of the real probe. The location and orientation of the virtual dynamic cryoprobe was updated in real time in the scene graph by the optical tracking device. The color of the virtual dynamic probe was changed to blue once it was on-line (aligned) and on-point to the virtual static probe as shown in Fig. 1(c). Stereo vision helped to hit the target faster than mono-vision [4].

Once we had successfully inserted the cryoprobe as described above, freezing the tumor started by sending argon gas through the cryochamber at 300 bar resulted to the temperature on tip of the cryoprobe to be $-180 \, ^\circ C$. Temperatures below $-40 \, ^\circ C$ and 1-cm zone of normal tissue including the cryolesion are considered necessary conditions for adequate ablation. During and after a freezing period of 20 min, visualization of the 3D temperature distribution within frozen region was essential to monitor the effectiveness of the procedure. To compute a new 3D temperature map, a new 3D MRI volume was required. The volume was acquired just prior to the end of freezing cycle. A segmentation algorithm was employed to define the frozen region. Fig. 1(d) shows the frozen tumor as a blue-colored object. The segmented frozen region as well as temperature reading from the temperature sensor inside the cryoprobe were used to compute 3D temperature maps. A detailed description of the algorithm that computes 3D temperature maps can be found in Ref. [5].

The information contained in the 3D temperature map can be visualized in two different ways, namely isotherm surface or 3D colored surface object typically on the segmented tumor surface. Using GUI, one can easily request an isosurface of any temperature. When an isosurface of $-40 \, ^\circ C$ was requested, two sets of data were calculated, isosurface and temperature distribution on tumor surface. We visualized isosurface as a transparent object with a specific color whereas tumor as an opaque object having many different colors. Similar color on isosurface and on tumor indicates that the regions had same temperature. This means we can easily point to regions on tumor that were colder (blue color) or warmer (red color) than $-40 \, ^\circ C$ as shown in Fig. 1(e). There are certain regions of tumor appearing outside the isotherm surface. This means that such areas are inadequately frozen and are needed to be treated differently. One possibility is to insert a second cryoprobe.
Fig. 1. Demonstration of cryoprobe insertion in (a)–(d). Transparent isosurfaces and colored temperatures on the tumor in (e)–(f).
Fig. 1(f) depicts an isosurface of $-20 \, ^\circ\text{C}$ and illustrates that surface temperatures on tumor are within $-20 \, ^\circ\text{C}$. This type of 3D visualization of surfaces in colors with depth information can be seen as a decision support system to terminate the procedure, insert another cryoprobe, or adjust temperature/pressure of the gas.

The graphical user interface as shown in Fig. 2 provides additional settings like opaque/transparent liver surface, different viewpoint location, stereo camera separation angle/distance, cryoprobe location save, different slice orientations, and window/level. Different viewpoint location means, for instance, two surgeons working on opposite side of the table can view the same object from their respective viewpoints.

4. Conclusion

An interactive 3D visualization scheme for cryotreatment has been proposed as a tool to navigating, controlling, and validating the procedure. A user-friendly and intuitive GUI provides access to a wide range of functions that can easily be used to speed up the
procedure. We also conclude that stereo-vision helps to hit the target much faster than mono-vision and provides enhanced information like temperature distribution and decision support to continuing or terminating the procedure. There are plans to extend the scope of the scheme for other surgical procedure like radio frequency treatment of liver tumors.

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**References**


