Realistic and Dynamic Simulation of Needle Implantation in Brachytherapy

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Abstract. We present a realistic and dynamic simulation method of the needle implantation in brachytherapy. The needle is firstly modeled as a polygon model and then its position and orientation are dynamically and automatically located using a magnetic tracking technology. Two buffers that reserve the result of the volumetric rendering and geometric rendering are mixed in the context of image-level hybrid volume rendering. Thereafter pre-planning of virtual catheters and the interactive and vivid simulation of needle implantation in brachytherapy are carried out. The realistic enhancement ways such as depth weight, shadow and 3D cutting view are also proposed in this paper.

1 Motivation

In brachytherapy, the key technology is how to control and implant the catheters to targeted position. With the guidance of computer, the visualization and tracking of needle help the users understand and supervision the ongoing and coming situation. Aims to improve the implantation quality and support more visual effect, we enhance the simulation of the implantation of needle in the context of realistic and dynamic visualization and navigation. Following are our method.

2 Methods

2.1 Modelling

The advantage of geometric model instead of volumetric model lies in two aspects:

- Geometric model makes the rendering more realistic and lifelike.
- Volumetric model is impracticable for dynamic simulation of needle.

In our methods, the needle is modeled as a thin and one-side pointed tube-like polygon model. The ratio of the length to the width is the same as the practical size of hospital needle.

2.2 Localization

2.2.1 Measurement of needle position

As described in the prior work [5][6], the localization of needle is performed on the assistance of the magnetic tracking system which measures its position and orientati-

on in the electromagnetic field transmitted by the transmitter of the system. Before the navigation, two pre-processes: calibration and registration have to be carried out manually which implement two tasks: calculate the local coordinate of needle and bring the virtual volumetric data coordinate into the real patient coordinates.

2.2.2 Calibration

The actual distance from the receiver to the receiver location could not be measured directly because the receiver package encloses its origin. So the vectors between them and the direction of needle axis are determined by the calibration proced-ure which composes of two steps:

- Vectors Computing
  Firstly, two vectors are computed: from the receiver origin to the tip of needle and from the receiver origin to the axis of needle.
- Matrix Synthesis
  Obtained vectors are displacement vectors from the local coordinate of the receiver and represent the position and orientation of needle relating to the recorded sensor data. Hence the calibration can be performed by utilizing 4x4 rigid transformation matrix.

2.2.3 Registration

Furthermore, to bring the real world to the virtual world i.e. the acquired volume data together with the real patient location in the same coordinate system, the registration between patient coordinate and volume dataset is implemented after the calibration. Here we take using of the landmarks matching for registration. The calibrated needle is used for markers identification on the body of the patient while the markers in the volume dataset are searched semi-automatically based on four features:

- The region of the markers preserves different intensity from the other region (in some cases it holds the highest)
- The markers lie on or outside of the body
- The markers have a sphere-like shape
- The region of the markers is disconnected from the other region.

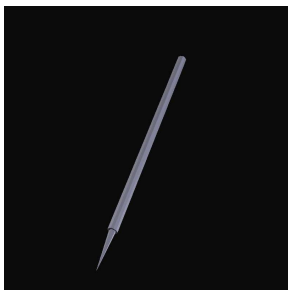

Fig. 1. 3D Model of needle

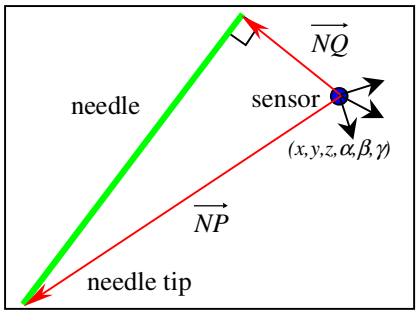

Fig. 2. Two calibrated vectors

Over-estimated candidates are selected manually for the final definition of the landmarks. Then the registration is performed by solve a set of over-estimated equations [2][3].

2.3 Visualization

The image produced by the ray-casting algorithm (based on the InViVo environment developed by A7 medical visualization group in Fraunhofer IGD [4]) is saved in a temporary buffer. During navigation, if the volume dataset is stable corresponding to the viewpoint, this buffer can be reused without time-consuming redrawing.

The geometry in the whole scene including the virtual needles is drawn into a temporary buffer using the accurate scan line algorithm interactively. The projecting and viewing matrix are calculated from the 6DOF data of sensor.

In each frame the geometry buffer is mixed with the volume buffer. This image-level blending operation is superior to the traverse level and the transfer function level mixing due to its interactivity for a dynamic simulation, i.e. the dynamic property of the geometry scene.

Some realistic enhancement methods such as depth weight, 3D cutting plane viewing and the shadow of the needle projected in the volume are implemented (Fig3,4 and 5).

2.4 Planning of Virtual Needles

By using the dynamic linking list, the initialization, insertion, deletion and visualization of virtual catheters is executed for the planning of the predefined position and direction of needles.

The creation of virtual needles can be performed expediently either by the tracker pointing on the patient or by mouse triggering and dragging in 3D rendering window and 3-directional slice windows. The quantitative information about virtual needles are then stored and transferred in system database.

2.5 Simulation of Needle Implantation

Three slice windows and one 3D window expose four views of the same volume dataset and the implantation of the needle, which simulates the whole procedure of

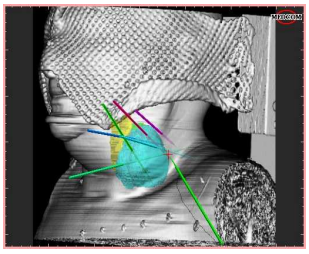

Fig. 3. Hybrid volume rendering

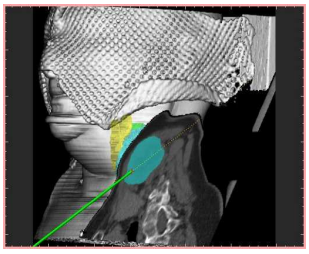

Fig. 4. 3D Cutting plane viewing

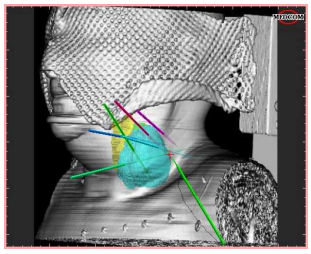

Fig. 5. Pre-planned virtual needles

needle movement, rotation and implantation interactively and quickly. Assisted with the free hand navigation system, users can implant the catheter in arbitrary angle and spatial position, obtain the information about where the needle is, how far is the needle inside the body, how close the needle is to the target and following the actions defined in the planning phase. Furthermore, the visualization of needle projection in 2D slice and real-time 3D cutting plane viewing help the users understand the spatial relationship and reveal the interior structure of the patient body.

3 Results

The simulation of the needle implantation shows the vision impact to the user, where the needle is, and how far is the needle with respect to the target tumor. On the base of the free hand navigation that was firstly developed by S.Walter and G. Strassmann [5][6], our new implementation improves the rendering realism and keeps the interactivity and dynamics of the operation, which are vital to the whole preplanning and intra-operation in brachytherapy. The described system affords an interactive and accurate implantation of the catheters for the preplanning, intra-operation and post planning in brachytherapy based on an interactive navigation in the pre-acquired volume data set. The accuracy of this needle navigation system has been evaluated with a phantom [6][7]. In a series of 120 placements of a needle of a length of 20 cm the accuracy is between 2.0 mm and 4.1mm which is a significant improvement of the conventional method which was evaluated to have an accuracy between 6.1 mm and 11.3 mm. The electromagnetic tracking system used in this system suffers as all electromagnetic systems do from its sensitivity to metal in the working range.

4 Literature

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