

PATH PLANNING SIMULATION FOR 3D ULTRASOUND GUIDED NEEDLE BIOPSY SYSTEM

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Abstract - We propose a path planning simulation system for 3D Ultrasound guided needle biopsy. This system is designed to accurately take a 3D biopsy specimen from an abdominal focal lesion without puncturing a blood vessel or pass through ribs. The introduced system tracks the 3D position of the biopsy needle and visualizes the needle in 2D and 3D in real time format. This new designed system gives the physician the optimal pathway to get a biopsy before puncturing the patient and visualizes this pathway in real time during the flythrough movement. Real time visualization of the needle in MPR and 3D volume of interest is performed. Experimental results on an in-vitro phantoms and water path phantoms showed promising results of this system.

I. INTRODUCTION

The only absolutely certain way to diagnose a cancer is by getting a cell sample (Biopsy) and examining the cells under a microscope. Biopsy can be done by putting a needle into the area of suspected lesion, and sucking out some cells to be examined. Visualization of the entire biopsy needle with 2D Ultrasound can be difficult, and the inherent 2D nature of the imaging technique requires skills in appropriately moving the scanning transducer in coordination with needle insertion.

Virtual reality in medicine-computer graphics and interaction techniques were proposed in [1]. Virtual surgery in a (tele-) radiology framework was designed and presented in [2]. Intraoperative ultrasound for guidance and tissue shift correction in image-guided neurosurgery was introduced in [3].

Computer aided surgery planning and rehearsal at Mayo clinic was introduced in [4]. Image guidance of breast cancer surgery using 3D ultrasound images and augmented reality visualization was implemented and discussed in details in [5].

Comparison of core needle breast biopsy techniques: freehand versus three-dimensional US guidance was proposed in [6]. Follicle aspiration with interactive three-dimensional imaging as a step toward real-time puncturing under three-dimensional ultrasound control was proposed in [7]. Evaluation and biopsy of recurrent rectal cancer using three-dimensional endosonography was performed in [8]. Methods for predicting mechanical deformation in the breast during clinical breast biopsy were introduced in [9]. In this paper we propose a path planning simulation system for 3D-Ultrasound guided needle biopsy.

II. SYSTEM DESCRIPTION

The introduced system consists of an electromagnetic locator (Ascension Technology) with two sensors. Each sensor can measure its 6 degrees-of-freedom relative to a fixed transmitter; the accuracy of the locator used is 0.2 mm which is suitable for our study. The first sensor is attached on the transducer of a conventional 2D-Ultrasound system and the second sensor is attached on the needle. We use a frame grabber card to capture the video signal from the 2D ultrasound machine which acquires 25 fps for PAL format and 30 fps for NTSC format (Matrox Meteor II). Figure 1 shows a block diagram of the proposed system.

III. 3D IMAGING SYSTEM AND NEEDLE CALIBRATION

During calibration we compute the transformation matrix between images scanned by the probe and the sensor mounted on the probe which is essential for determining the exact position of the images relative to the reference point (Electromagnetic transmitter) [10]. Needle calibration is performed by computing the transformation matrix between the tip of the needle and the sensor mounted on it. This process is essential in registering the tip of the needle with the scanned volume (Same reference point).

IV. VOLUME ACQUISITION

First we start a 3D Ultrasound scan of the volume of interest by moving the probe smoothly over the volume. During scanning, the system acquires images from the 2D ultrasound machine and also acquires position and orientation readings from electromagnetic sensor. Patient controlled respiration and limbs movement is assumed during acquisition.

V. 3D RECONSTRUCTION

3D reconstruction associates each image with its position and orientation relative to reference point (Transmitter). Relative transformation between images is then calculated to register images inside an empty volume. Gaps inside the reconstructed volume are interpolated linearly to get a better-filled volume quality [10-11]. Figure 2 shows an

example of a rendered volume with MPR for a hepatic focal lesion.

VI. 3D SEGMENTATION

3D segmentation is performed on the volume of interest (VOI) for calculating volumetric measurements and for surface rendering. 3D center of gravity (COG) for the VOI was calculated. Segmentation is done by 2 methods:

1. Manual segmentation

Rotational contours that define the border of the VOI were selected manually. Manual segmentation is fast and suitable in a case of noisy volume.

2. Semi-automatic segmentation

Gradient Vector Flow active contour model (GVF) [12] was used. Active contour model is suitable for well bounded and less noisy objects as in Figure 3.

VII. PATH PLANNING

Pathway between the needle and the tumor is rendered in real time. The physician selects the optimal pathway taking into consideration that it does not cut a blood vessel or pass through a bony structure such as ribs.

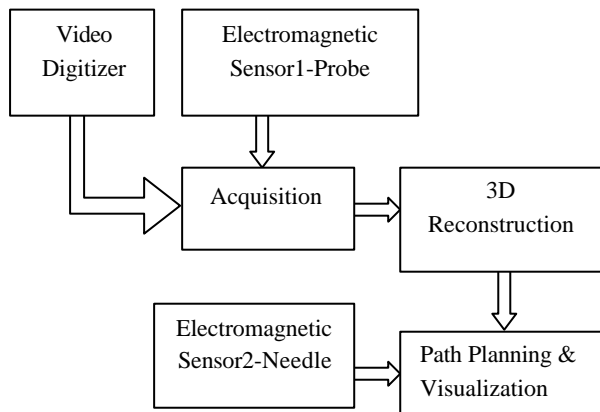


Figure 1

Block diagram of the proposed 3D guided biopsy system

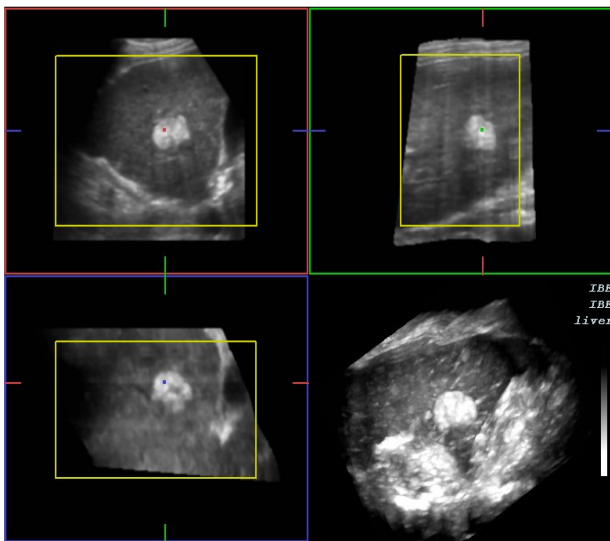


Figure 2

3D volume rendering of hepatocarcinoma focal lesion tumor.

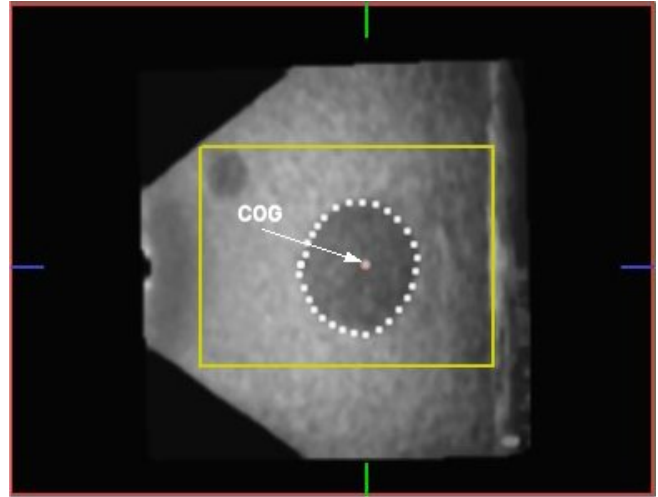


Figure 3

Contour surrounding the object to be segmented and the COG at the center.

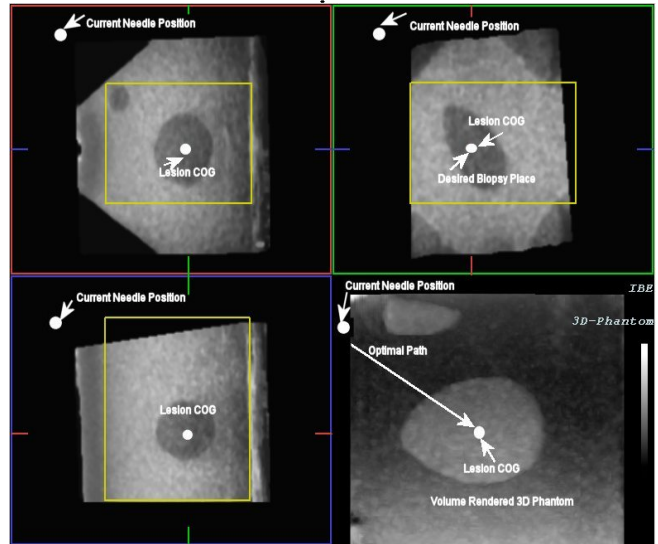


Figure 4

MPR of a 3D phantom and 3D volume rendered image during flythrough.

During path planning, 6 windows are visually displayed for the physician to show the spatial relation of the needle position with respect to the x-y, y-z, z-x images (MPR), the spatial relation of the needle with the volume rendered tumor, the spatial relation of the needle tip position with the optimal pathway to the tumor, and finally the 2D ultrasound image of the needle in the tissues (Acquired real time 2D images). 3D virtual navigation can be performed by moving the needle tip toward the patient and visualize it relative to the pre-scanned volume before the real biopsy operation.

VIII. FREE FLYTHROUGH MODE

In this mode the operator moves without guiding lines that indicate the optimal pathway to the VOI. In this mode the location of the needle is calculated and displayed within MPR images. As shown in Figure 4, the physician moves the needle based on his visual inspection of the displayed MPR-Needle and Volume-Needle spatial relations.

IX. GUIDED FLYTHROUGH MODE

In this mode, 3D segmentation for the VOI is performed and COG of the segmented VOI was calculated. A guiding line is drawn from the tip of the needle to the COG of the VOI to show a guiding path for the physician. Also audible sound from the system directs the physician toward the optimal pre-calculated pathway. Figure 5a shows a segmented 3D VOI displayed as a surface rendered image in yellow color palette. Figure 5b shows the rendered VOI, the 3D needle tip position, the needle path during flythrough, the optimal path drawn within the tumor, the COG of the tumor with respect to 3D position of the needle, and an RGB color plotted code which indicates the guided position to the VOI in 3D. In Figure 5b blue color indicates that the needle tip is moving toward the VOI, green color indicates that the needle is within the segmented VOI, and red color indicated that the needle tip is far from the VOI (Required biopsy region). In this mode MPR-Needle and Volume-Needle relations is also displayed in real time.

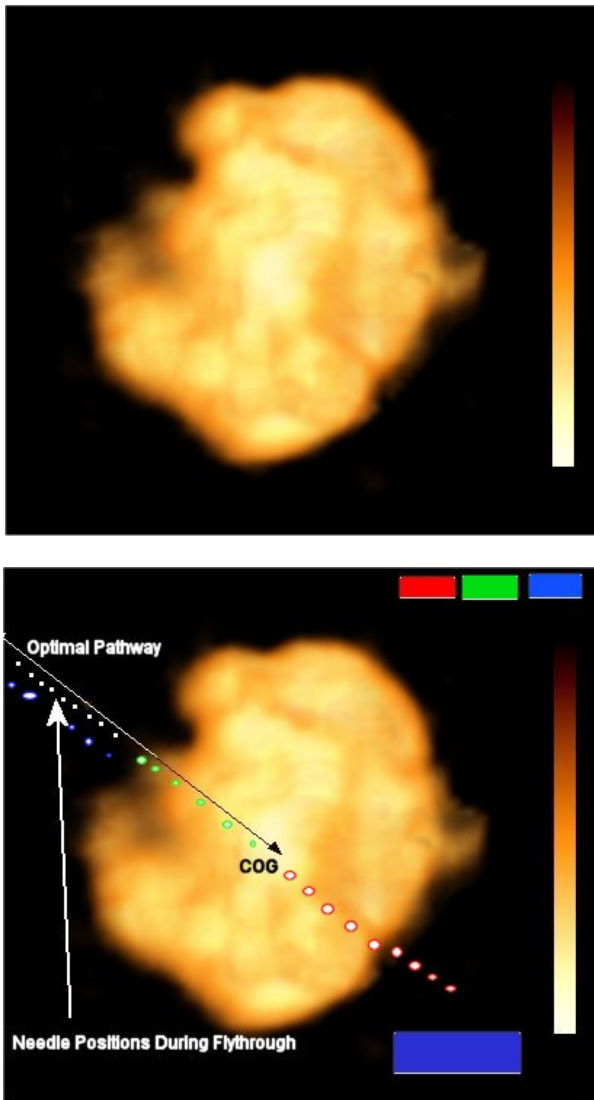


Figure 5

a) 3D segmented tumor shown in yellow color code b) Movement of the needle inside and in the near and far neighborhood of the tumors.

X. CONCLUSIONS

The new proposed simulation system for path planning of 3D Ultrasound guided needle biopsy can be of clinical importance since it gives an exact overview for the needle, tumor, and surrounding tissues in real time so that physician does not cut a blood vessel or takes a wrong biopsy. This system is designed to accurately take a 3D biopsy specimen from abdominal focal lesions. Experimental results on in-vitro phantoms and water path phantoms were promising. These promising results suggest an in vivo clinical study to experiment this system on animals. This biopsy system can be practiced for accessible soft tissues such as liver, spleen, kidney, and prostate. Elasticity of soft tissues during flythrough process as well as the respiration pattern of the patient is to be corrected in the future.

XI. ACKNOWLEDGMENTS

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