CT Guided Liver Tumor Biopsy Framework

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Abstract. Liver tumor biopsy is the first step of a liver cancer diagnosis. Accuracy of liver cancer diagnosis depends upon how precisely the sample is collected from the right location. The ultrasound-guided biopsy procedure is subjective and painful to patient. CT guided biopsy framework assists medical experts in planning biopsy needle path before performing the procedure. In this framework, first, CT image acquired, and 3D models are created for liver, skin, liver tumor, bone, and liver blood vessels using 3Dirac CT datasets. Second, an algorithm designed for biopsy needle insertion path recommendation. At the last 3D simulation generated. Needle insertion starts from the skin and ends at the tumor site. The recommended needle path does not carry bone and major blood vessels. The designed framework suggests two possible paths that medical experts can select and allow to make a further modification in that path. 3D simulation of needle insertion shown to medical experts for the evaluation. According to their comments, methods are producing promising results. The proposed framework may utilize for teaching-learning procedures for junior medical experts. Automatic biopsy needle path recommendations are perquisites for generating augmented reality tools and robotic biopsy systems.

1. Introduction

The liver is located below the thorax and on top of the pelvic region. The liver is the biggest internal organ in humans and performs plenty of body functions [1]. Liver cancer is one of the life-threatening diseases among other kinds of abnormality. Liver primary cancer (Hepatocellular Carcinoma) is initiated at the liver site and secondary cancer transferred by other organs, also known as metastasis. The liver is the first suspect organ to confirm the metastasis stage of different body parts cancer. Liver cancer incidence is increasing and its the fifth major cause of mortality worldwide [2],[3].

One of the significant causes of healthcare expenditure of patients with chronic liver disease is Hepatocellular Carcinoma (HCC). Computed Tomography (CT) guided liver biopsy procedure is performed by inserting a needle to the liver percutaneously, and the sample is collected to perform histopathology analysis for cancer diagnosis. Abdominal CT imaging is essential for the diagnosis and image-guided interventions of liver and liver tumors. Ultrasound and CT guided procedures are now the mainstays in managing liver diseases, avoiding unnecessary surgeries for obtaining biopsy specimen or removing liver tumors. Image-guided interventions fasten the workflow and reduce patient discomfort as daycare procedures are done under local anesthesia. Liver segmentation
algorithms assist in diagnosing and prognosis of various liver disorders such as cirrhosis and liver tumors. Once the liver tumor is seen on CT imaging, the next step is to obtain a biopsy from the tumor for histopathological analysis to confirm the diagnosis. Liver tumor biopsy is mainly required to diagnose and determine the stage of cancer, and later for treatment evaluation. After the diagnosis of liver cancer is established, based on the staging (severity), it may be treated by various procedures such as surgery, radiation therapy, and thermal ablation, irreversible electroporation, etc. [4].

Ultrasound image-guided biopsy procedure is one of the favorable image-guided interventions. Some of the limitations of ultrasound-guided biopsies, like the lesion are not visualized as in obese patients; performance is very subjective, intervening bowel, etc. [5].US-guided biopsy procedures are very subjective, which needs to make objective to reduce operator dependency. Nowadays, most of the ultrasound-guided interventions are replacing with CT guided interventions to overcome the limitations of ultrasound. In this article, CT guided liver tumor biopsy framework is designed to counter the limitation of US-guided procedures.

2. Materials and methods

2.1 Data sets

The 3D Image Reconstruction for Comparison of Algorithm Database (3D-IRCAD) was utilized for this experiment. 3D-IRCAD Contains 22 subjects' 3D abdominal CT images along with liver and tumor ground truth. The image dimension is 512 x 512 pixels in the axial plane; the number of slices ranges from 74 to 225. The resolution in the X and Y directions ranges from 0.57 mm to 0.81 mm [6].

2.2 Methodology

We have designed a CT-guided biopsy framework comprising four steps; image acquisition, image segmentation, biopsy path recommendation, and 3D simulation (Figure 1). This framework will assist the clinician in planning the needle path in CT guided biopsy procedures. A biopsy gun needle is inserted from the skin to the tumor along the safest and shortest path avoiding bones and vital structures. Usually, a clinician selects an appropriate needle insertion path based on the imaging findings and personal experience.

![CT Guided Biopsy Framework](image)

**Figure 1.** CT guided biopsy framework

2.2.1 Skin and Bone Segmentation
Skin is the body's outer surface; the liver biopsy procedure requires the outer shell to decide the entry point of needle insertion. In CT, the differences in Hounsfield units or gradient image, skin pixels have the highest gradient as it is surrounded by air. Skin carries a specific HU and gradient. A combination of thresholding and image gradient method is used to segment skin (Figure 2). Skin segmentation procedure further corrected by the morphological operations.

![Figure 2. Result for skin segmentation](image)

**Figure 2.** Result for skin segmentation (a) DICOM Image, (b) 2D Slice, (c) 3D Skin Segmentation

The liver is surrounded by the lower ribs of the right rib cage and situated below the diaphragm. Before performing the biopsy, it is essential to know the ribcage's exact location, which decides the track for needle insertion. Although bony structures show high contrast in CT images, their detection, identification, and correct segmentation remains a challenge [7]. The knowledge of the rib cage is very necessary for any CT guided biopsy procedure. A threshold-based approach has been used for the segmentation of ribcage. This method has performed an automatic and reliable image thresholding approach to segment the ribcage from CT images. We concluded the value of ‘t ‘to be 50±2 on an average, which separates the ribs as the foreground from the background image [8]. Later, the segmented images are projected on a 3D platform, and the results obtained were found to be quite promising, as shown in Figure 3. Rib cage border outline marked accurately, which is a prerequisite for biopsy planning because bone parts should be avoided from needle path trajectory.

![Figure 3. Rib cage segmentation](image)

**Figure 3.** Rib cage segmentation (a) Reference Image (b) Segmented image (c) 3D view

2.2.2 Liver and Its Blood Vessels and Tumour Segmentation
Cascaded dilated deep residual network (DDRN) was utilized for segmenting liver, tumor, and blood vessels [9]. The abdominal CT image was segmented into three classes liver tissue, tumor, and blood vessels. After segmenting all body parts such as the rib cage, skin, liver, blood vessels, and liver tumor were superimposed in the same image (Figure 4).
Figure 4. Result of liver segmentation and internal entity segmentation

2.2.3 Needle Path Planning
Accurate placement of the needle tip inside the tumor tissue is challenging, and critical structures and anatomical obstacles must be avoided. The first step is to select the tumor for biopsy if they are multiple. Criteria include viable tumor volume having viable (living) tissue (avoiding necrotic or dead tissue within) and distance from the skin entry site. Our implementation recommends the insertion point based on the shortest distance with the minimum number of obstacles. Needle path planning algorithm works based on cost function minimization concerning individual voxel within the path.

All steps are as follows:

Step 1: Selection of the target tumor if multiple tumors present within the liver.
Step 2: Selection of 2D axial slice, which carries the maximum area for the selected tumor in step one.
Step 3: Calculate the centroid of tumor selected in step two.
Step 4: Determine the centroid of the vertebra column present in the 2D axial view, which is selected in step two.
Step 5: Draw an arc at the concerning centroid of vertebra toward outer skin passed through tumor centroid width of the tumor's major axis.
Step 6: Consider all possible insertion points with respect to arc across the skin surface.
Step 7: Find the shortest and safest path with respect to the selected arc in the sixth step.
Step 8: Recommend a minimum two cost function path to a medical expert for their opinion and further corrections.

The same process may be performing for the skin arc, which covers the liver area's maximum size. The shortest distance with minimum cost function may be the selected possible safest path. We use a 2D axial slice to determine the target point, making it easy to identify the location in Z-Direction. The next step is to choose the mask of possible entry points on the skin surface. We introduce a distance graph that, for every point of the pathway. This reduces the time needed for validating a possible path.

3. Results
For further enhancing the understanding of the whole biopsy procedure, a 3D simulation is also provided (Figure 5). This view helps in accurately locating the tumor and allows the inspection of the chosen needle pathway in a volumetric manner to provide a full spatial context for the biopsy needle. The simulation results were presented to three radiologists doing CT guided interventions in a tertiary care institute with such facilities for the validation in planning and performing CT guided biopsies and ablation of the liver tumors.
4. Conclusion

In this study, CT guided liver tumor biopsy planning is demonstrated. First, skin, bone, liver, blood vessels, and liver tumor were segmented using different segmentation algorithms. Skin was segmented using gradient operation followed by thresholding and morphological operation. After segmenting the rib cage, liver and inner components of the liver were segmented using DDRN. All blood vessels, including the portal vein, hepatic artery, and hepatic veins, were considered under the same classification. Our radiologists’ team suggested that different phases of CT data should include and segment the portal vein and the hepatic artery separately. Blood pressure within the artery is greater than the veins, so the cost function weightage should be different for the artery and the veins to get exact planning. The needle path can be shifted due to the movement of the abdominal organs during respiration. Respiration gating should also be implemented along with an automated navigation system using augmented reality. Earlier, multiple CT scans were acquired to perform a single biopsy procedure; therefore, implementing the 3D simulations for tumor biopsy will reduce patient discomfort and excess x-ray radiation dose to the patient and the healthcare workers.

5. References

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