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Mixed Reality for Minimally Invasive Bone Tumor Ablation

Djamel Aouam[123], Ronan Querrec[23], Thierry Duval[25], Nadia Zenati[1], and Chafiaa Hamitouche[45]

[1] Centre de développement des technologies avancées (CDTA)
daouam@cdta.dz
nzenati@cdta.dz
[2] Lab-STICC CNRS UMR 6285
[3] ENIB Ecole Nationale d'Ingénieurs de Brest
querrec@enib.fr
[4] LaTIM - INSERM UMR 1101
[5] IMT-Atlantique Brest
thierry.duval@imt-atlantique.fr
chafiaa.hamitouche@imt-atlantique.fr

Abstract

Minimally invasive intervention requires accuracy and practice as it can be vital in complex and narrow places. In this paper we propose a solution based on augmented reality (AR) for the ablation of bone tumors. Our proposal deals with the preoperative and intraoperative phases of the procedure. The first part consists of the segmentation and 3D reconstruction of the structures of interest. The second part consists of the visualization in AR.
This solution is intended to facilitate the tasks of surgeons and radiologists when planning RF needle insertion and trajectory in order to avoid excessive exposure to X-rays, which is a phase that requires more precision and knowledge of the morphology of the mass tumor. The second part offers AR assistance based on the planning of the preoperative phase. The solution we proposed is based on the use of HoloLens 2 headsets to provide better AR visualization and assistance.

Keywords: Augmented Reality, Bone Tumor Ablation, Minimally Invasive Intervention, 3D Imaging

1 Introduction

Bone tumors represent 6% to 10% of cancers. Besides, an efficient diagnosis and treatment planning should involve orthopedic surgeons, radiologists, pathologists and oncologists. They localize tumor regions MRI-based medical imaging technologies [8, 4], which helps them take an appropriate decision regarding tumor removal techniques [11]. Several ablation procedures was experienced such as:

laser photocoagulation, alcoholization, radiofrequency, microwaves, cryoablation. The ablation procedure is performed in two stages: (1) preoperative phase which concerns the planning of the trajectory of the needle using segmented MRI images, (2) intraoperative phase where the needles are inserted into the bone tumor for RF Ablation. These advanced minimally invasive surgical techniques work without incision on the human body and improve the recovery speed of the patients. However, several difficulties are faced in tumor localization, may compromise the success of the procedure and increase X-ray exposure.

AR could be an alternative solution [8, 12, 7, 5, 2] to improve the efficiency of bone tumor ablation. This technology offers surgeons the possibility of better perceiving the tumor in the organ thanks to a 3D display. This could be possible if we displayed a realistic 3D tumor with real shape and size. To overcome this problem, tumor segmentation and 3D reconstruction are necessary. The purpose of segmentation is to separate the regions of interest (ROI) from other parts of the body to perform quantitative measurements, as well as to correctly locate the desired object to improve the diagnostic phase. Another challenge is to generate realistic 3D models to improve the identification and quantification of bone tumors.

This work aims to improve the surgical procedure by using 3D segmentation, reconstruction and AR for the localization and quantification of tumor regions. We provide surgeons with an interactive AR platform to view and interact with the 3D structures from real patient MRI images. We also display needle trajectories to aid in the ablation procedure.

2 Materials and methods

The proposed framework is composed of two modules: 3D Segmentation and Reconstruction Module (S3DM) and AR Rendering and Interaction Module (ARIM). For S3DM, we developed a segmentation algorithm to identify and delineate the tumor area on an MRI volume images of a humerus with a tumor. For the segmentation we followed several steps, the first consists in the localization of the tumor by surgeon manually. Next, we perform image contrast enhancement by combining parametric linear and logarithmic stitching algorithms to improve image quality. We then apply segmentation to identify the bone tumor. The following is the implemented algorithm:

- Apply histogram equalization method to enhance MRI images.
- Calculate the erosion of a binary image A by the expression below:

$$\epsilon B\left(A\right)=A\Theta B=\left\{z|Bz\subset A\right\} \tag{1}$$

- Calculate the gradient based on the erosion value Ei,j.
- Apply the watershed on the binary image to generate a binary mask and separate the region of interest.
- Enhance the mask using the equation below:

$$\left(IF\left(BBi,j\parallel CRi,j\right)=0,CBBi,j=0\right) \tag{2}$$

- Apply the watershed to the gradient of image to obtain segmented tumor zone.

On segmented images, we use 3D reconstruction. Based on the original MRI segmented pictures, a 3D mesh was created using the 3D slicing program [9].

In terms of ARIM, we've incorporated AR to create a realistic and comprehensive 3D representation of the bone tumor. Using the Unity3D graphics engine, we created an interactive AR visualization application. We construct the 3D model in the ARIM module to provide a realistic 3D bone tumor display and interaction in which the tumors are segmented and demarcated in 3D. According to the comparison study conducted by [10], we employ an OST-HMD such as the Hololens2, which has greater performance. with the OST-HMD The user sees virtual data projected on a semi-transparent projection surface [2].The 3D bone tumor is projected onto the patient's actual morphology. The needle's 3D trajectory is also shown.

3 Results

Our segmentation method works well. Using the evaluation measures, Table 1 compares our segmentation method to existing segmentation strategies [1, 3].

The Segmentation Quality (SQ) metric measures how well our segments correspond to their core truths. When this number approaches 1 (or 100% if we normalize), it signifies that our projected segments (TP) true positive match the ground truth better. on the same photographs of our subject Our method's accuracy is demonstrated by the findings.
Based on the segmentation results, 3D slicer is used to obtain a 3D model of the humerus highlighting the tumor mass for better vision and perception of the tumor mass.
The HoloLens 2 was used for the projection of the 3D model of the organ and the tumor. Our solution allows the surgeon to visualize the organ and manipulate the organ while using the empowerment of their own hands by applying natural interaction (hand interaction).

The proposed solution is not only limited to visualization but also allows to perform the needles insertions and trajectories. Then we project the 3D model with planning on the real organ using an appropriate registration method and identification so that it is an assistance. Moreover, one of the advantages of using an OST-HMD is that the headset user directly sees the real environment and the virtual object is superimposed on the lens to enrich the real environment [2]. Figure 1 illustrates some sequences of our proposed model.

4 Conclusion

We proposed a system based on the projection of the real 3D organ in AR. In order to provide better accuracy and precision for the surgeon and reduce the error rate compared to methods based on the projection of simple annotations [6]. Our application offers better assistance given the surgeon a better vision and knowledge of the structures of interest. In addition, our system is not limited to visualization [8] but offers the possibility of interacting with the anatomical structures and planning insertions with more precision compared to 2D planning.

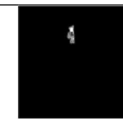
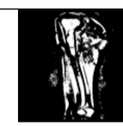
	Accuracy	Sen	FM	Precision	MCC	Dice	jaccard	Spec	
Our method	0.99846	0.88525	0.93913	1	0.94014	0.93913	0.8825	1	
Level set	0.99182	0.99621	0.47775	0.31422	0.55717	0.47775	0.31384	0.99181	
GraphCut	0.8531	1	0.92026	0.8523	0.17481	0.92026	0.8523	0.035854	
ResNet	0.98396	0.40073	0.51094	0.70475	0.52426	0.51094	0.34313	0.99642	
Bensen	0.13922	0.96458	0.24412	0.13974	-0.16969	0.24412	0.13903	0.00025	

Table 1: Evaluation index comparison results

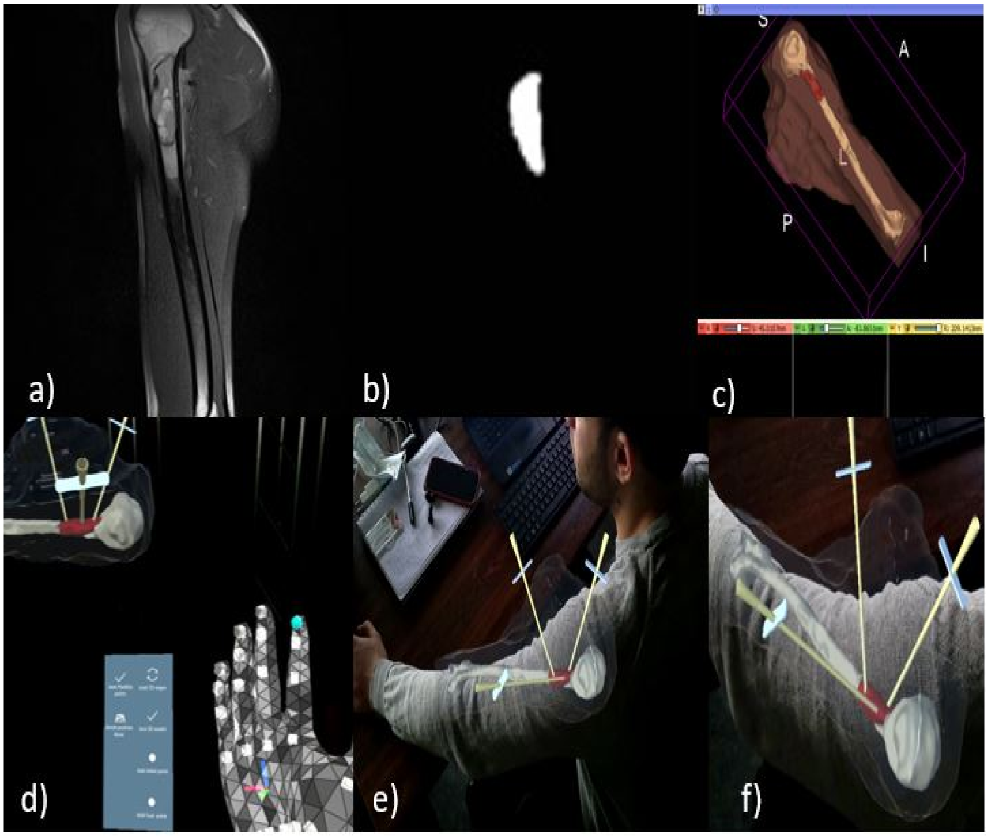


Figure 1: 3D Model, a)MRI Image, b) Segmentation result, c) 3D reconstruction, d) Hand menu , e) and f) Projection of the 3D model on the real organ

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