VisibleUS: From Cryosectional Images to Real-Time Ultrasound Simulation

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Abstract

The VisibleUS project aims to generate synthetic ultrasound images from cryosection images, focusing on the musculoskeletal system. Cryosection images provide a highly accurate representation of real tissue structures without artifacts. Using this rich anatomical data, we developed a ray-tracing-based simulation algorithm that models ultrasound wave propagation, scattering, and attenuation. This results in highly realistic ultrasound images that accurately depict fine anatomical details, such as muscle fibers and connective tissues. The simulation tool has various applications, including generating datasets for training neural networks and developing interactive training tools for ultrasound specialists. Its ability to produce realistic ultrasound images in real time enhances medical education and research, improving both the understanding and interpretation of ultrasound imaging.

CCS Concepts

• ***Computing methodologies*** → ***Ray tracing; Image-based rendering;*** • ***Applied computing*** → *Interactive learning environments;*

1. Introduction

Ultrasound imaging plays a crucial role in healthcare, particularly in the assessment of the musculoskeletal system. Its real-time, non-invasive, and cost-effective nature makes it an essential tool for diagnosing soft tissue injuries, guiding procedures, and monitoring rehabilitation [PMGU17]. However, interpreting ultrasound images requires significant training, as the appearance of anatomical structures depends on various factors such as probe positioning, tissue composition, and the specific ultrasound settings used, so ultrasound simulation systems seems necessary to train new experts.

Various simulation methods for ultrasound image generation have been explored. Ray-tracing-based simulators as [RPAS09, APD*24] model acoustic wave propagation, including transmission, absorption, and reflection, to enhance realism. However, these methods primarily rely on surface contours, limiting their ability to represent internal tissue structures. To address these challenges, the VisibleUS project aims to develop a new ultrasound simulation method based on cryosection images, which provide high-resolution anatomical details. Using this data, a ray-tracing-based simulation approach is proposed to generate synthetic ultrasound images that closely resemble real scans, focusing on musculoskeletal structures and faithfully reproducing key features such as muscle fibers, connective tissues, and bone surfaces.

Cryosection images are high-resolution anatomical photographs obtained from frozen cadaver slices, offering detailed structural information of tissues such as muscles, bones, and nerves. Unlike CT or MRI, cryosections provide true-color anatomical visualization, making them a valuable tool for medical education and simulation. Despite advancements in ultrasound simulation, these images have not been used as a primary data source. The "Voxel Man" project [BLH*04] has explored their educational potential, but without real ultrasound simulation. In Figure 1 an example of a cryosection image is presented and the 3D volume representation of the associated labels.

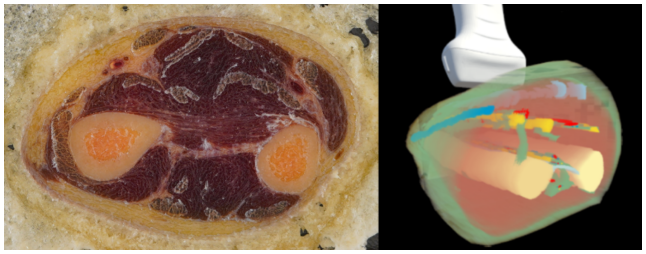

Figure 1: *Example of a cryosection image of the forearm, showing the ulna and radius bones (left) and 3D volume representation of the labeled tissues (right).*

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Figure 2: *Ultrasound and 6DoF motion data acquisition(left), Immersive educational tool(middle) Interactive ultrasound training tool(right)*

2. The VisibleUS Project: real-time ultrasound simulation

The main outcome of this project is an algorithm to generate real-time ultrasound images using a ray-tracing approach applied to high-resolution cryosection images. The algorithm models key ultrasound interactions, including echoes generated at tissue boundaries, energy absorption within tissues, and speckle formation based on real anatomical structures instead of artificial noise. Ray-tracing allows sampling 3D textures of RGB cryosectional images and labeled data to acquire internal tissue details to enhance realism and maintain real-time performance.

2.1. Interactive educational tools

To demonstrate the method's practical value, we developed different interactive training tools available in both web and VR versions (Figure 2 center and right). Users can manipulate the ultrasound probe and adjust imaging parameters like zoom, gain, and pressure deformation. This interactivity enhances learning by helping students understand how probe movement affects ultrasound imaging, with the help of the cryosection images, making it a valuable educational resource.

2.2. Synthetic ultrasound images dataset

A further outcome of the simulator is the capacity to create datasets with the corresponding ultrasound simulation and pixel-level tissue annotations (see Figure 3). This eliminates manual or semi-automatic labeling errors, which are challenging for this type of imagery. The generated dataset can be used for training AI-based systems, the performance of which is heavily dependent on data quality. Additionally, the project's resulting dataset includes real medical images from the cadaver, such as CT scans and 6DoF-positioned ultrasound images (Figure 2 left), making it suitable for training models that correlate these different imaging modalities.

3. Conclusions

In conclusion, the VisibleUS project introduces a novel approach to ultrasound image simulation, leveraging cryosectional images to achieve a high level of realism, even in the internal composition of tissues. The scope of the project encompasses the development of training tools based on the novel simulation and the creation of pixel-level labelled datasets. This represents a substantial advancement in both medical training and ultrasound imaging research.

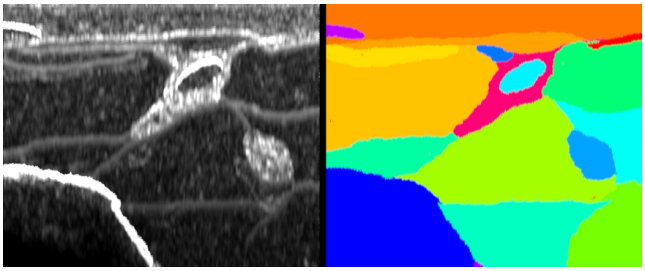

Figure 3: *Simulated Ultrasound image (left) and corresponding labels of each tissue (right).*

4. Acknowledgments

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