Real-Time Ultrasound Image Synthesis for Deformable Soft Tissue Simulation in Surgery

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INTRODUCTION

A number of recent studies in surgical robotics have focused on developing realistic surgical simulation environments or platforms that can be used to train surgical AI agents, especially through reinforcement learning (RL) or imitation learning (IL). However, the focus so far has been primarily on simulating visually plausible scenes in terms of the RGB image observation, such as how the endoscopic camera image looks when tissue deforms or is burnt after cauterization. Other medical imaging modalities, such as ultrasound (US) imaging, are frequently used during surgeries, which may also be used as observations for surgical AI agents. Therefore, simulating such images is an important step towards training agents that can utilize other imaging modalities. This work proposes a real-time US image synthesis method for surgical soft body under randomized deformation.

MATERIALS AND METHODS

The COLE algorithm [1] is a convolution-based method that trades simulation accuracy for improved speed. It synthesizes US images by applying a 1D convolution between the point spread function (PSF) of the imaging system and the projected signal of all point scatterers on each radio frequency (RF) line. Point scatterers are virtual points distributed within the simulated tissue that represent acoustic reflectors. Their placement and amplitude simulate how tissue structures reflect ultrasound waves. Each scatterer is assigned an amplitude to ensure that the resulting synthetic US images look plausible.

Previous work [2] has shown success in using the material point method (MPM) for simulating soft body and deformation during surgery. MPM utilizes a number of discrete points (particles), each with its position and velocity at the current time step. This naturally allows the tracking of the ultrasound scatterers with the deformation of the MPM tissue, by deforming the dense US point scatterers through interpolating displacements from the underlying, coarser MPM points. The scatterer deformation is achieved by first recording the neighbouring MPM points of each scatterer before the start of the simulation, and then update the scatterer locations by interpolating the displacements of the neighbouring MPM points. This enables real-time ultrasound image generation that can track tissue deformation, although it does not account for the motion-based effects such as Doppler shifts. For many robotic learning applications, especially those focused on control policies or visual-servoing rather than quantitative evaluation, this should provide sufficient level of plausibility.

RESULTS AND DISCUSSION

Thanks to its efficiency, COLE allows real-time performance when synthesizing US images. Fig 1 shows example US images (linear scan), synthesized during tissue deformation.

The COLE algorithm is very fast. However, the algorithm has limitations in terms of the accuracy of the simulated images. Nevertheless, it is a good trade-off between speed and accuracy, making it suitable for real-time applications, including simulation-based surgical AI training.

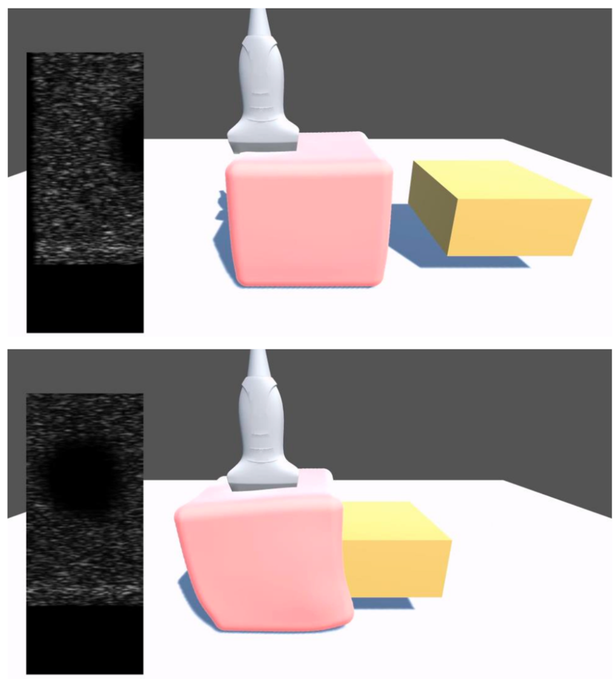

Fig 1 US image synthesis with soft tissue deformation.

CONCLUSIONS

We explored real-time US image synthesis for surgical AI training, while the soft tissue is simulated using MPM. US images can be simulated when the tissue deforms randomly as the US point scatters tracks the deforming MPM points. Further improvements, such as GPU acceleration will be implemented in the next step.

REFERENCES

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