Biomechanical modeling of probe to tissue interaction in robotic ultrasound scanning

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Introduction

To improve the precision and repeatability of current manual breast biopsy procedures, the MURAB project relies on a robotic system equipped with an ultrasound probe and a steerable needle guide. Due to the highly deformable nature of the breast, biopsy intervention planning is performed by taking into account tissue deformations induced by probe-tissue contacts. Selection of the appropriate model to describe this kind of interaction requires to find the optimal trade-off between three main performance criteria: accuracy, speed and stability.

Methods

The SOFA framework is exploited to evaluate three main approaches that can be used to model US probe-tissue interaction: using (i) penalty forces, (ii) constraint forces and (iii) prescribing the displacement of the breast mesh surface nodes. The considered scenario consists of a rigid probe in contact with the deformable breast tissues, whose behavior is described by a Neo-Hookean constitutive law exploiting patient-specific properties.

Results

While all methods achieve similar accuracy, different trade-offs between stability and speed are obtained, in particular by methods explicitly modeling the contacts. Overall, prescribing surface displacements is the approach with best performances, but it requires prior knowledge of the contact area and probe trajectory. However, this does not represent a limitation within a robotic framework, where the robot motion is planned in advance.

Conclusion

Different strategies exist for modeling probe-tissue interaction, each able to achieve different compromises among accuracy, speed and stability. The choice of the preferred approach highly depends on the specific requirements of the medical application. Since the presented methodologies can be applied to describe general tool-tissue interactions, this work can represent a reference for researchers seeking the most appropriate strategy to model anatomical deformation induced by the interaction with medical tools.