A general framework for automatic robotic palpation

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Palpation process using elastography has been studied for malign tissue localization. This technique has been applied in ultrasound and magnetic resonance imaging modalities. However, the ultrasound features make it suitable for robotic-assisted systems in real-time [1], [2], [3]. The basic principle of ultrasound elastography is based on quasi-static mechanic compression of a target tissue with an ultrasound probe to obtain its elastic parameters. This parameters are generally imaged in an *elastogram* for visual purposes.

The procedure to obtain an elastogram in hospitals is done by hand. Nevertheless, drawbacks like abrupt changes in force compression and motion stability of the hand affect the elastogram quality an sometimes ending in a wrong diagnosis. The dexterity of a robot can tackle these issues using a stable compression motion of the ultrasound probe. Very few investigations have been undertaken regarding the use of ultrasound elastography in robot-assisted procedures. These works are related to the field of laparoscopy. For example, a snake-like robot was presented in [4], where a micro ultrasound probe attached at the distal part of the robot was used to find hard lesions by palpation motion. The da Vinci surgical robot (Intuitive Surgical Inc.) was also used to obtain elastic information of a tissue of interest by controlling the motion of a laparoscopic 2-D ultrasound probe [5]. Using a similar framework, in [6] a mechanical vibrator placed on the skin of the patient was proposed instead of controlling the motion of the ultrasound probe. However, none of these works use the strain information to control the robot.

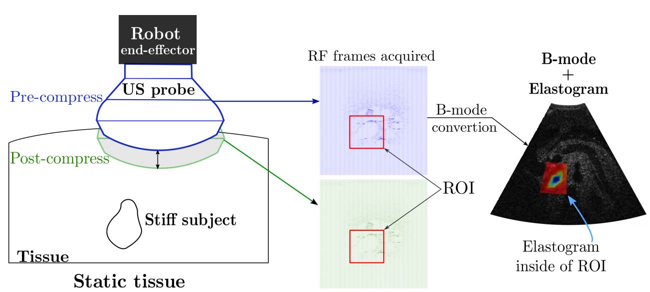

Fig. 1. **Robotic elastography process**. From left to right: mechanical compression with the ultrasound probe over a static soft tissue; radio frequency signal frames acquired for the pre- and post-compress states; b-mode image with a elastogram overlaid on a region of interest (ROI).

In this work, we present a robotic approach to estimate and use the elastogram in real-time to assist in ultrasound elastography procedures (Fig. 1). The base of this framework is the fusion of three hierarchical control tasks. The main task is the automatic compression motion essential for the elastogram estimation. The elastogram is estimated using an extended block matching algorithm for motion estimation for the pre- and post-compression states, and the common least-squared strain filter. In lower priority, an automatic centering task involves visual servoing based on strain information. This second task allows to maintain the largest stiff tissue detected in the center of the field of view of the ultrasound probe. The largest stiff tissue is localized using a connected component algorithm and image moments to compute its centroid. The last task, is the teleoperation of the orientation of the ultrasound probe. This enables the user to control the orientation of the probe, through a graphic user interface or a remote haptic device.

This approach has been applied in preliminary ex-vivo experiments (some of them presented in [7], [8], [9]) demonstrating the feasibility of the use of the strain map in robotic systems.

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References

[1] C. Nadeau and A. Krupa, "Intensity-based direct visual servoing of an ultrasound probe," in *IEEE Int. Conf. on Robotics and Automation*, Shanghai, 2011, pp. 5677–5682.

[2] P. Chatelain, A. Krupa, and N. Navab, "Optimization of ultrasound image quality via visual servoing," in *IEEE Int. Conf. on Robotics and Automation*, 2015, pp. 5997–6002.

[3] D. Lee and A. Krupa, "Intensity-based visual servoing for non-rigid motion compensation of soft tissue structures due to physiological motion using 4d ultrasound," in *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, San Francisco, 2011, pp. 2831–2836.

[4] H. T. Sen, N. Deshmukh, R. Goldman, P. Kazanzides, R. H. Taylor, E. Boctor, and N. Simaan, "Enabling technologies for natural orifice transluminal endoscopic surgery (N.O.T.E.S) using robotically guided elasticity imaging," in *Medical Imaging: Image-Guided Procedures, Robotic Interventions, and Modeling*, vol. 8316. SPIE, Feb 2012, pp. 83 161Y–83 161Y–8.

[5] S. Billings, N. Deshmukh, H. J. Kang, R. Taylor, and E. M. Boctor, "System for robot-assisted real-time laparoscopic ultrasound elastography," in *Medical Imaging: Image-Guided Procedures, Robotic Interventions, and Modeling*, vol. 8316. SPIE, Feb 2012, pp. 83 161W–83 161W–8.

[6] C. Schneider, A. Baghani, R. Rohling, and S. Salcudean, "Remote ultrasound palpation for robotic interventions using absolute elastography," in *Medical Image Computing and Computer-Assisted Intervention*, Nice, 2012, pp. 42–49.

[7] P. A. Patlan-Rosales and A. Krupa, "Automatic palpation for quantitative ultrasound elastography by visual servoing and force control," in *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, Daejeon, 2016.

[8] P. Patlan-Rosales and A. Krupa, "A robotic control framework for 3-d quantitative ultrasound elastography," in *IEEE Int. Conf. on Robotics and Automation, ICRA'17*, Singapore, May 2017.

[9] ——, "Strain estimation of moving tissue based on automatic motion compensation by ultrasound visual servoing," in *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'17*, Vancouver, Canada, September 2017.