

Rigid motion compensation with a robotized 2D ultrasound probe using speckle information and visual servoing

Alexandre Krupa¹, Gabor Fichtinger^{2,3} and Gregory D. Hager³

¹ INRIA Rennes-Bretagne Atlantique,

Campus Universitaire de Beaulieu, 35042 Rennes, France

E-Mail: alexandre.krupa@irisa.fr

² School of Computing, Queen's University, Kingston, Canada

E-Mail: gabor@cs.queensu.ca

³ Engineering Research Center, Johns Hopkins University, Baltimore, MD 21218, USA

E-Mail: hager@cs.jhu.edu

Abstract

This work deals with the use of speckle information contained in 2D B-mode ultrasound images to control the displacement of a robotized ultrasound probe with a visual servoing control scheme. The objective is to automatically synchronize the displacement of a conventional 2D ultrasound probe held by a medical robot in such a way to stabilize the image of a moving soft tissue. Such a workable method operating on 2D ultrasound images could be exploited in a host of clinical applications. For example, in diagnostic ultrasound imaging, one could automatically move the ultrasound probe to maintain the optimal view of moving soft tissue targets; or in biopsies and localized therapy procedures, one could synchronize the insertion of needles or other surgical tools into a moving target observed in live ultrasound.

The approach we propose makes only use of the speckle information contained in ultrasound images to estimate the relative displacement between a target region, that moves with the soft tissue, and the observed ultrasound image plane. Traditionally, ultrasound speckle has been considered to be noise, and much effort has been devoted to eliminating or reducing speckle in ultrasound images. Speckle, however, is not random noise. It results from coherent reflection of very small cells contained in soft tissue. As a result, it is spatially coherent and remains highly correlated over small elevation motions of the ultrasound probe.

In our approach, the motion estimation problem is decoupled into motion within plane and motion out-of-plane. For the former, an image region tracker is used to provide the in-plane motion. For the latter, we developed an original method based on the speckle information contained in the images. Our method online estimates the signed elevation distance of several patches fixed along a grid on the target region from speckle decorrelation measurement. The out-of-plane translation and orientations of the plane containing the target region with respect to the observed ultrasound plane are then obtained by fitting a plane to the 3D coordinates of the patches.

To compensate the motion we propose to automatically move the medical robot holding the probe in such a way to minimize the relative position between the target region and the observed ultrasound plane. This

was achieved by implementing a hybrid visual control scheme that consists of independently controlling the in-plane and out-of-plane degrees of freedom motions (DOF) of the ultrasound probe, respectively by a 2D image-based visual servoing technique and a 3D visual servoing technique.

This concept was first validated in simulation [1] by controlling a virtual probe interacting with a static ultrasound volume acquired from a medical phantom. The approach was then demonstrated [2] for rigid translation motions combining a translation along the image X axis (in-plane translation) and elevation Z axis (out-of-plane translation) in an experimental setup consisting of an ultrasound speckle phantom, a robot for simulating tissue motion, and a robot controlling the ultrasound probe directly from the speckle information.

Initially this method only worked locally about the target region since it required a minimum of speckle correlation between the target region and the observed image. However speckle correlation can decrease rapidly when out-of-plane large motion are considered. To overcome this limitation we have recently improved the method [3] by robustly estimating the signed elevation distance of each patch containing in the target region by using a memory array of successive intermediate patches that preserve speckle correlation. This last method was experimentally validated for full rigid motion (3 translations and 3 rotations) using a 6-DOF medical robot holding an ultrasound probe and an ultrasound speckle phantom that was manually moved by hand. Fig. 1 shows successive external views of the experiment during the motion automatic compensation. A video of this experiment is accessible on the web link: <http://www.irisa.fr/lagadic/demo/demo-speckle-comp/speckle-comp-eng.html>

Our concept has the advantage to not rely on segmentation of structure of interest and shows promise for ultrasound-guided procedures that require real-time motion tracking and compensation.

References

- [1] A. Krupa, G. Fichtinger, G. Hager. Full motion tracking in ultrasound using image speckle information and visual servoing. In *IEEE Int. Conf. on Robotics and Automation, ICRA'07*, Pages 2458-2464, Rome, Italie, April 2007.
- [2] A. Krupa, G. Fichtinger, G.D. Hager. Real-time tissue tracking with B-mode ultrasound using speckle and visual servoing. In *Int. Conf. on Medical Image Computing and Computer-Assisted Intervention, MICCAI'07*, N. Ayache, S. Ourselin, A. Maeder (eds.), LNCS 4792, Volume 2, Pages 1-8, Brisbane, Australie, October 2007.
- [3] A. Krupa, G. Fichtinger, G.D. Hager. Real-time motion stabilization with B-mode ultrasound using image speckle information and visual servoing. *The International Journal of Robotics Research, IJRR*, Special Issue on Medical Robotics, Ayache, N. and Desai, J. (Eds.), to appear, 2009.

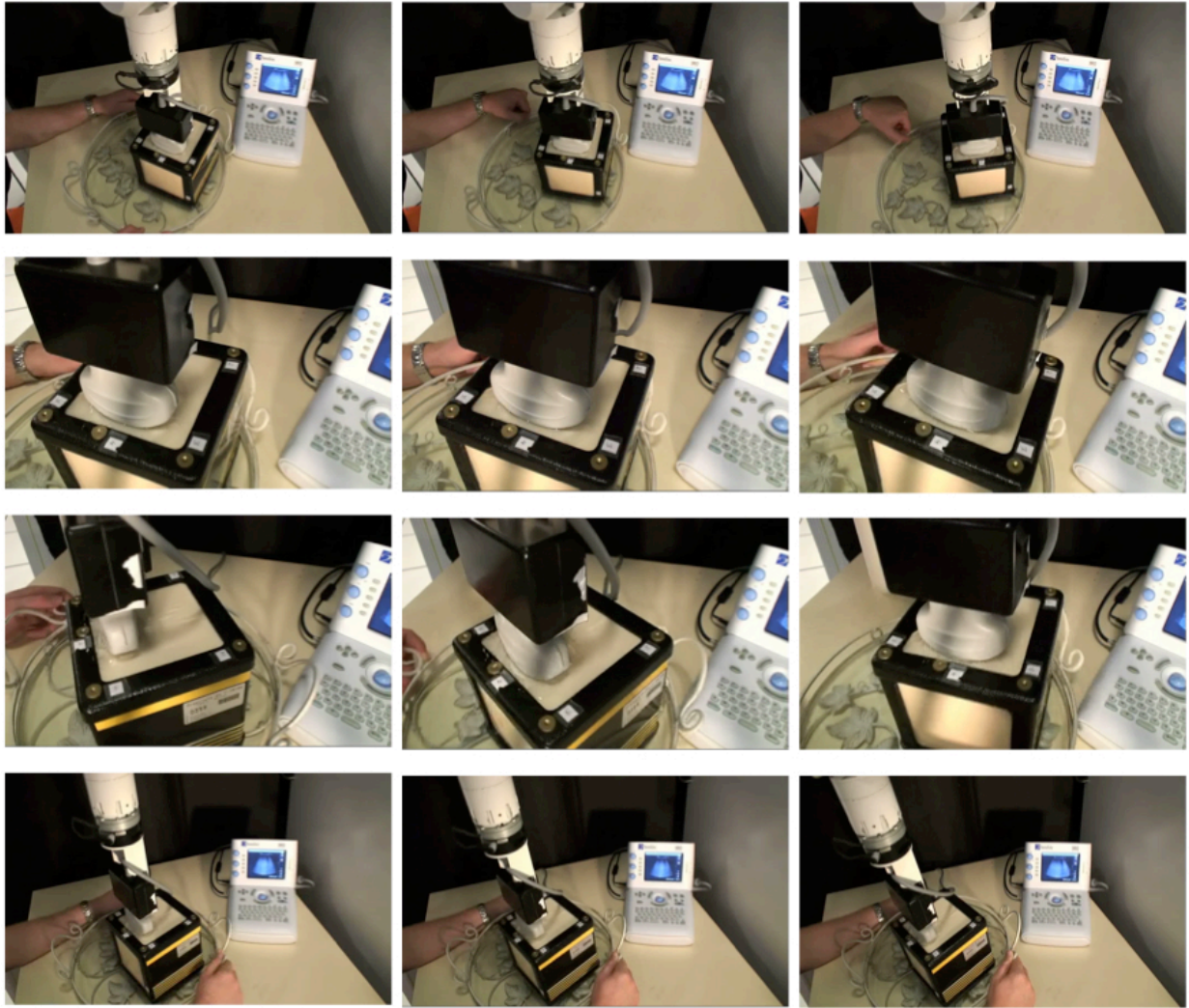


Fig. 1 Successive external views showing the experiment. The robotized ultrasound probe automatically compensates 6-DOF motions that were manually applied to an ultrasound phantom.