Simulating Dynamic Ultrasound Using MR-derived Motion Models to Assess Respiratory Synchronisation for Image-Guided Liver Interventions

Erik-Jan Rijkhorst, Daniel Heanes, Freddy Odille, David Hawkes, and Dean Barratt

Centre for Medical Image Computing, Department of Medical Physics and Bioengineering, University College London, London, United Kingdom
{e.rijkhorst,d.heanes,f.odille,d.hawkes,d.barratt}@ucl.ac.uk
http://cmic.cs.ucl.ac.uk

Abstract. Tracked intra-operative ultrasound can be registered to real-time synthetic ultrasound derived from a motion model to align pre-operative images with a patient's anatomy during an intervention. Furthermore, synchronisation of the motion model with the patient's breathing can be achieved by comparing diaphragm motion obtained from the tracked ultrasound, with that obtained from the synthetic ultrasound. The purpose of this study was to assess the effects of spatial misalignment between the tracked and synthetic ultrasound images on synchronisation accuracy. Deformable image registration of 4-D volunteer MR data was used to build realistic subject-specific liver motion models. Displacements predicted by the motion model were applied to acoustic parameter maps obtained from segmented breath-hold MR volumes, and dynamic B-mode ultrasound images were simulated using a fast ultrasound propagation method. To prevent synchronisation errors due to breathing variations between motion model acquisition and interventional ultrasound imaging from influencing the results, we simulated both the synthetic and the tracked ultrasound using a single motion model. Spatial misalignments of up to ±2 cm between the tracked and synthetic ultrasound resulted in a maximum motion model breathing phase error of approx. 3 %, indicating that respiratory synchronisation of a motion model using tracked ultrasound is relatively insensitive to spatial misalignments.

Keywords: dynamic ultrasound, motion models, synchronisation, breathing, image guidance.

1 Introduction

Minimally- and non-invasive liver interventions, such as radio-frequency ablation and high-intensity focused ultrasound, rely on accurate image guidance to compensate for intra-operative respiratory motion. Over the past few years, several

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methods for quantifying organ motion using 4-D CT or MR based motion models have been presented [1–4]. Such models can be used in combination with intraoperative imaging, such as B-mode ultrasound, to spatially align pre-operative images to the patient's anatomy during an intervention [5–8], allowing for a more accurate treatment of a target region.

Apart from spatial registration, accurate real-time temporal synchronisation of a motion model with the patient's breathing is equally important [4, 9]. To achieve this, a surrogate breathing signal needs to be available during intervention, for example by tracking skin markers [1] or using a navigator to track diaphragm motion [2, 4, 10].

The purpose of this study was to assess the effects on synchronisation accuracy of a pre-operative motion model with a subject's breathing due to spatial misalignment between tracked interventional ultrasound and real-time synthetic ultrasound derived from the motion model. Deformable image registration of free-breathing volunteer MR data was used to build a subject-specific liver motion model as a function of breathing phase. To obtain acoustic parameter maps, breath-hold MR volumes were segmented into liver, blood, lung, and ribs. The maps were deformed by applying the displacements predicted by the motion model, and a fast ultrasound propagation simulation was used to compute dynamic B-mode ultrasound images. One such simulated ultrasound sequence was used to represent the tracked ultrasound, while a second sequence, computed at a slightly different location to simulate spatial misalignment, represented the real-time synthetic ultrasound. A navigator window was positioned at the diaphragm in both simulated sequences, from which surrogate breathing signals and a motion model phase error were computed.

2 Materials and Methods

We propose the following scenario for synchronising a motion model to a subject's breathing during an intervention (Fig. 1). Prior to intervention, real-time

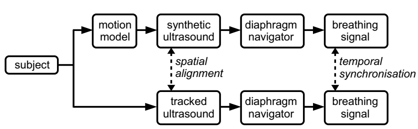

Fig. 1. Scenario for synchronising a motion model to a subject's breathing. Note that in this study both the tracked and synthetic ultrasound were simulated using a single motion model.

MR images are acquired and deformable image registration is used to obtain a motion model. High-resolution breath-hold MR images are segmented into different tissue types to allow the computation of simulated ultrasound images.

During intervention, tracked dynamic B-mode ultrasound images of the moving diaphragm are continuously acquired. Using the tracking information, these