Schnelle Ultraschallsimulation für computer assistierte Leberchirurgie

Fast ultrasound simulation for computer assisted liver surgery

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Purpose

During percutaneous liver surgery, a surgeon often navigates under 2D freehand ultrasound guidance. The surgical planning, however, is often done on the basis of a pre-operative CT scan. Consequently, the surgeon has to perform the visually demanding task of mentally correlating 3D volume slices to ultrasound 2D slices during the surgery.
To aid the orientation of the surgeon during operation planning and execution, our aim is to make this task easier by complementing the in-vivo ultrasound images by simulated ultrasound images, computed from the pre-operative CT scan.

Materials and Methods

In order to provide this facility in a fast way, we opted against a detailed physically motivated simulator. This is because at the current level of computer and software technology, there is still no hope of employing this class of ultrasound simulators in a real-time setting on standard PC hardware.
Instead, we generate simulated ultrasound images by applying linear digital filters, based on the statistical properties of the ultrasound speckle textures.
The method employed in this work is to compute at first the autocorrelation function of different tissue types in homogeneous regions. The speckle pattern of a given tissue type is modeled by its autocorrelation function. We construct the transfer function of a linear shift invariant filter in Fourier domain from a given prescribed autocorrelation function by applying the well-known Wiener-Khinchin-Theorem.

To digitally synthesize a speckle pattern, we convolve Gaussian white noise with the above constructed transfer functions. The filtering is carried out in Fourier domain with the help of the FFT algorithm. Thus, for every speckle pattern encountered in our scenario, we constructed a transfer function, thus obtaining a filter bank.
We generate a simulated ultrasound image from the output of this filterbank by switching according to the tissue type labels of a presegmented liver CT scan. The tissue type labels are computed by using the segmentation algorithms of our tool HepaVision.

Evaluation:

We evaluated our image synthesis method by checking against the physically based Field II ultrasound simulator [1] as our gold standard , using scatterer distributions of a cyst phantom and a kidney phantom. To do this, we first estimated autocorrelation functions from homogeneous patches of data generated by Field II and constructed a suitable filter bank.
We further checked against images of in-vivo ultrasound scans.

Discussion:

We find that if sufficient high quality data for estimating the autocorrelation function is employed, the generated speckle pattern reflects real life textures very closely.
Among a number of possible variations of our image synthesis methods that have been tested and evaluated, the above outlined method yields the best results in terms of image quality and computational speed of the algorithm.
However, the generation of nonlinear effects like reflections still requires further refinement of the currently employed method. A further topic is the integration into our planning tool InterventionPlanner, and evaluation trough clinical partners.

Acknowledgement:

Supported by the DFG (PE 199/9-2)
[1] Jørgen Arendt Jensen: Field II Ultrasound Simulation Program, http://www.es.oersted.dtu.dk/staff/jaj/field/