Abstract

This Ph.D. project was carried out at the Center for Fast Ultrasound Imaging, Technical University of Denmark. The goal was to improve existing imaging techniques in order to make them suitable for real-time three-dimensional ultrasound scanning. This dissertation focuses on the synthetic aperture imaging applied to medical ultrasound. It is divided into two major parts: tissue and blood flow imaging.

Tissue imaging using synthetic aperture algorithms has been investigated for about two decades, but has not been implemented in medical scanners yet. Among the other reasons, the conventional scanning and beamformation methods are adequate for the imaging modalities in clinical use - the B-mode imaging of tissue structures, and the color mapping of blood flow. The acquisition time, however, is too long, and these methods fail to perform real-time three-dimensional scans. The synthetic transmit aperture, on the other hand, can create a B-mode image with as little as 2 emissions, thus significantly speeding-up the scan procedure.

The first part of the dissertation describes the synthetic aperture tissue imaging. It starts with an overview of the efforts previously made by other research groups. A classification of the existing methods is made, and a new imaging technique, the “recursive ultrasound imaging” is suggested. The technique makes it possible to create a new image after every emission. This opens further the possibility for visualizing the blood flow. Various aspects of the scan procedure are considered, among them: the use of sparse one- and two-dimensional arrays; the use of multiple elements in transmit to create virtual sources of ultrasound; the use of virtual sources of ultrasound to improve the resolution of the images in the elevation plane; the use of temporal and spatial encoding to increase the signal to noise ratio. In many of the mentioned areas, the author presents the existing state of the art, and adds his personal contributions.

The second part describes blood flow estimation using synthetic aperture techniques. It starts by introducing the velocity estimator based on the time shift measurement of the received signals. This estimator fails to estimate the velocity when applied on the radio frequency signals formed by synthetic aperture techniques. The failure is caused by the motion artifacts, and the second part continues by developing a new model for them. Based on this model a novel motion compensation scheme is presented. The velocity can successfully be estimated from the motion compensated images. The standard deviation and the bias are both within 2 %. The estimation of blood flow using synthetic transmit aperture ultrasound is further extended by developing a scheme of how to modify the existing blood flow estimators. In the new approach images \( n \) and \( n + N \), \( n + 1 \) and \( n + N + 1 \) are cross correlated, where \( N \) is the number of emissions for one image. These images experience the same phase distortion due to motion and therefore have a high correlation without motion compensation. The estimate of the cross-correlation
is improved by averaging the estimates obtained from the pairs of frames \([n, n + N], [n + 1, n + 1 + N], \) and so on up to \([n + N - 1, n + 2N - 1]\). The advantage of the approach is that a color flow map can be created for all directions in the image simultaneously at every emission, which makes it possible to average over a large number of lines. This makes stationary echo canceling easier and significantly improves the velocity estimates. Only 8 emissions per plane are necessary to create the color flow map. Scanning 12 cm in depth, up to 800 planes can be obtained, making it possible for real-time three-dimensional tissue and blood-flow imaging.