Chapter 7

Summary and conclusions

The main objective of this thesis was to implement image processing tools to extract information from images acquired with sonoelastography and crawling wave (CrW) sonoelastography. These tools were applied to two important clinical applications: Prostate cancer detection and measurement of thermally ablated lesions in liver. Therefore, the contributions of this thesis are related to the development of image processing tools, and to the performance evaluation of sonoelastography and CrW sonoelastography in the above-mentioned clinical applications.
7.1 Development of image processing tools

In this thesis, algorithms to enhance the quality of the images; extract location and size information of discrete lesions; and provide viscoelastic properties of the imaged tissue were developed.

A semi-automated segmentation algorithm to measure discrete lesions in sonoelastographic images was proposed. The algorithm was used to measure thermally ablated lesions in sonoelastographic images in vivo. Resulting segmentations of the algorithm showed good agreement with pathology data and manual segmentation results. More importantly, inter- and intra-observer coefficients of variability were reduced and the time to segment a sonoelastographic image was decreased by a factor of 8. Additionally, the algorithm was adapted to perform segmentation in three dimensions and in shear velocity sonoelastograms.

A correlation-based algorithm to process CrW sonoelastography was proposed to extract shear velocity information from homogenous tissues. This algorithm was successfully applied to the measurement of viscoelastic properties of human prostate and veal liver tissues ex vivo.

Finally, motion filtering and slow time processing were proposed to enhance the quality of the CrW images by using the time relationship between frames in a CrW movie. As an additional advantage, the processing of the CrW movies generated a
quality metric image which was used to discard regions with poor signal to noise ratio in the image.

7.2 Evaluation of sonoelastography and CrW

Sonoelastography

Experiments were performed to establish a relationship between the intensity values displayed on a sonoelastographic image and the actual vibration amplitude of the tissue. These experiments characterized the response of the sonoelastographic imaging system implemented in the Logiq 9 US scanner used for all the experiments in this thesis. The study concluded that a combination of a low pulse repetition frequency and a wall filter with higher attenuation of low frequencies can be used to sensitize the sonoelastographic system to detect very low vibration amplitudes such as those of in vivo experiments.

Sonoelastography was applied to measure thermally ablated lesions induced in a porcine liver in vivo. Results suggest that sonoelastography, in combination with the segmentation algorithm introduced in this thesis, has the potential to be used as a complementary technique to conventional ultrasound for thermal ablation monitoring and follow-up imaging.
The performance of three-dimensional sonoelastography for prostate cancer detection was evaluated in *ex vivo* and *in vivo* experiments. Sonoelastographic findings were compared to histological results by employing image segmentation and registration tools. Sonoelastography showed an accuracy of over 80% for finding tumors larger than 4 mm in diameter in both experiments, and slightly underestimated their volumes.

Crawling Wave (CrW) Sonoelastography was used to detect cancer in excised human prostates and provide quantitative estimations of the viscoelastic properties of human cancerous and normal tissues. Results showed good spatial correspondence with histology. Additionally, the estimated shear velocities of cancerous and normal tissue are 4.75±0.97 m/s and 3.26±0.87 m/s, respectively. These results are in agreement with previous reports on the elasticity of cancerous and normal human prostate tissue and suggest that CrW Sonoelastography could be used to improve prostate cancer detection.

### 7.3 Future work

Higher contrast images, and therefore, a better detection rate of lesions, could be obtained by pushing the sonoelastographic experiments to higher vibration frequencies. This is true for both sonoelastography and CrW sonoelastography. However, higher attenuation over long distances will diminish the signal at higher frequencies, so better means of applying local vibration at higher frequencies...
(approaching 200 Hz or higher) need to be developed. Furthermore, in the case of CrW sonoelastography, the vibration sources need to be opposing each other. This configuration is particularly difficult for \textit{in vivo} experiments. Acoustic radiation force may provide a good alternative to create higher frequency and localized vibration sources.

In prostate cancer detection, performance of sonoelastography as a guidance tool for biopsy needs to be further investigated. Additionally, 3D results indicate that benign prostatic hyperplasia (BPH) may be also stiffer than normal tissue. In consequence, BPH nodules appear as deficits in sonoelastographic images. Therefore, a better and quantitative understanding of the viscoelastic properties of BPH (and other benign conditions) as compared to cancer is required. CrW sonoelastography may become a useful tool for this purpose.

In the measurement of thermally ablated lesions, minimally invasive ways to apply vibration to the tissue need to be investigated. Efforts to apply vibration transcutaneously have not shown good results. Alternatively, two options may provide a better performance: Using the RFA needle as a vibration source or applying an acoustic radiation force deep in the tissue.

The semi-automatic segmentation algorithm has room for improvement. Ways of initializing the algorithm can be investigated for particular applications. For example,
in the case of RFA treatment, detection of the RFA needle in B-mode images could be used to initialize the algorithm. The selection of the parameter $U$ can be understood as an optimization process. Currently, an extensive search is performed to find the best value of the parameter. The segmentation time of the algorithm could be reduced even more by applying optimization techniques such as maximum descent or simulated annealing algorithms. Finally, if the measurements require an increased resolution, a pyramid approach [102] to segmentation may speed up the time to perform them.