Chapter 8

Visualization and Segmentation Techniques in 3D Ultrasound Images

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Summary. Although ultrasonography is an important cost-effective imaging modality, technical improvements are needed before its full potential is realized for accurate and quantitative monitoring of disease progression or regression. 2D viewing of 3D anatomy, using conventional ultrasonography limits our ability to quantify and visualize pathology and is partly responsible for the reported variability in diagnosis and monitoring of disease progression. Efforts of investigators have focused on overcoming these deficiencies by developing 3D ultrasound imaging techniques using existing conventional ultrasound systems, reconstructing the information into 3D images, and then allowing interactive viewing of the 3D images on inexpensive desktop computers. In addition, the availability of 3D ultrasound images has allowed the development of automated and semi-automated segmentation techniques to quantify organ and pathology volume for monitoring of disease. In this chapter, we introduce the basic principles of 3D ultrasound imaging as well as its visualization techniques. Then, we describe the use of 3D ultrasound in interventional procedures and discuss applications of 3D segmentation techniques of the prostates, needles, and seeds used in prostate brachytherapy.

8.1 Introduction

Ultrasonography is an inexpensive and safe imaging modality that is widely used for different applications such as material defect detection, and diagnosis and staging of human disease. Conventionally, ultrasound images are two-dimensional (2D) making comprehension of complex three-dimensional (3D) structures and related applications including volume measuring, 3D anatomy display and animation difficult. In order to overcome this problem, 3D ultrasound imaging techniques have been developed in the past decade, which can reconstruct 3D ultrasound images of organs and tissues from acquisition of multiple conventional 2D images.

In Sections 8.2 and 8.3 we address the problems of acquisition and visualization of 3D ultrasound images. In Section 8.4, we introduce the application of 3D US techniques in interventional procedures, such as image-guided surgery.
and therapy. Finally, we discuss the use of 3D ultrasound for segmentation techniques used to segment the prostate (Section 8.5), needles (Section 8.6) and brachytherapy seeds (Section 8.7).

8.2 Basic Principles of 3D Ultrasound

Three-dimensional visualization of the interior of the human body has been a goal of diagnostic radiology since the discovery of x-rays. In the 1970s and 1980s, computed tomography (CT), ultrasound (US), positron emission tomography (PET), and Magnetic Resonance Imaging (MRI) have revolutionized diagnostic radiology by providing true 3D information about the interior of the human body. However, 3D visualization techniques were slower to develop, primarily because of the demanding computational requirements for 3D reconstruction and manipulation of the large amount of data in the 3D images. Thus, early systems presented the acquired 3D information as 2D images, requiring the physician to view multiple cross-sections of the anatomy and assemble the 3D information in his or her mind.

Medical ultrasound (US) imaging is a versatile and inexpensive imaging modality available in most hospitals in the world. Current US imaging produces images of high quality, making it an indispensable tool in the management of many diseases, as well as for providing image guidance for interventional procedures. Nevertheless, conventional US imaging still suffers from disadvantages, related to its 2D nature, which 3D imaging attempts to address. Despite decades of exploration, it is only in the past five years that 3D US imaging has advanced sufficiently to move out of the research laboratory and become a commercial product for routine clinical use.

8.2.1 Limitations of 2D US Imaging

The development of 3D US addresses the disadvantages of 2D US imaging that are related to the flexibility and subjectivity of the conventional 2D US exam. Specifically, 3D ultrasound developments address the following limitations:

- Because conventional ultrasound images are 2D, the operators must mentally transform multiple 2D images to develop a 3D impression of the anatomy and pathology during the diagnostic examination or during an image-guided interventional procedure. This imaging approach is time-consuming, inefficient, requiring an experienced operator, and can potentially lead to incorrect diagnostic or therapeutic decisions.
- Staging and planning of interventional procedures often requires accurate estimation of organ or tumor volumes. Current 2D US volume measurement techniques assume an idealized shape, and use only simple measures of the width and length in a few views. This practice leads to inaccuracy and operator variability in volume estimation.