Chapter 33

IVUS Image Processing Methodologies

Antonis A. Sakellarios
University of Ioannina, Greece

Christos V. Bourantas
Castle Hill Hospital, UK

Lambros S. Athanasiou
University of Ioannina, Greece

Dimitrios I. Fotiadis
University of Ioannina, Greece

Lampros K. Michalis
University of Ioannina, Greece

ABSTRACT

Intravascular Ultrasound (IVUS) is an invasive imaging technique that allows detailed visualization of the arterial lumen and outer vessel wall and permits characterization of the type of the plaque and quantification of its burden. Traditionally IVUS processing was performed manually. However, it became apparent that manual segmentation is time consuming, and the obtained results depend on the experience of the operators. To overcome these limitations and enhance the role of IVUS in clinical practice and research, several (semi-) automated methods have been developed that expedite detection of the regions of interest and/or characterization of the type of the plaque. In this chapter we review the available IVUS processing techniques and present the developed commercial solutions for IVUS segmentation and plaque characterization.

INTRODUCTION

Accurate evaluation of coronary artery pathology and reliable assessment of plaque burden requires visualization of the vessel wall with increased distinctness. Several invasive [intravascular ultrasound (IVUS), optical coherence tomography (OCT), angioscopy] and non-invasive imaging modalities [computed tomographic coronary angiography (CTCA) and magnetic resonance imaging (MRI)] are nowadays available that allows assessment of luminal pathology, quantification of plaque burden and characterization of the type of the plaque. Although invasive, IVUS remains the method of choice for the evaluation of the atherosclerotic process as it provides in real time two dimensional (2-D) cross-sectional images which portray in detail the lumen, outer vessel wall and the stent morphology and give information regarding the composition and the extent of the atheroma. The fact that
IVUS is reliable and quick to use has allowed its extensive utilization over the last two decades in assessing vessel wall pathology and understanding the atherosclerotic process.

At the beginning of IVUS imaging, the segmentation of the obtained sequence was performed manually. However, it became apparent that this procedure is laborious, time consuming and the accuracy of the obtained results depends on the operators’ expertise. To address these limitations, several methodologies have been developed which allow (semi)-automated segmentation of the IVUS sequence and computation of plaque volume and its composition. Some of these have been incorporated in commercially available systems that operate in a user-friendly environment and provide border detection and plaque characterization in almost real time. These features have rendered them useful in clinical practice and allowed their extensive use in the catheterization laboratory.

The present chapter discusses the available methodologies, developed for automated IVUS processing, and is organized as follows: in the background section we present the artefacts seen in IVUS highlighting the difficulties noted in IVUS processing. In the main focus section we analyze the developed IVUS border detection methodologies and the methods that allow characterization of the type of the plaque in grayscale IVUS images. In addition, we present the existing approaches for the automated identification of the end-diastolic IVUS frames and conclude with an overview of the available commercial systems which are currently available for IVUS processing.

**BACKGROUND**

Apart from the regions of interest (lumen, media-adventitia and stent border) and the plaque [which depending on its echogenisity can be classified as echolucent/soft (lipid rich) plaque, intermediate (fibrous) plaque, echo dense (calcific) plaque and mixed if it includes more than one acoustic subtypes] (Mintz et al. 2001) various artefacts are often seen in IVUS images which should be taken into consideration during the segmentation process (Figure 1). Some of these depend on the type of the catheter (mechanical or solid state) used, while others can be detected in all IVUS sequences. For example, the non-uniform rotational artefacts can be seen only in mechanical IVUS imaging and are due to asymmetric friction which leads the transducer to lag during one part of the rotation and whip through the other part of its 360° rotation resulting in geometrical distortion of the image. On the other hand the ring down artefact, the shadowing artefact, the reverberations and the blood speckles are seen in both mechanical and solid state IVUS imaging. The ring down artefact is due to signal disorganization and appears as a bright halo of variable thickness around the catheter while the shadowing artefact occurs when a structure with a marked difference in acoustic impedance (e.g. calcific plaque) blocks the transmission of the ultrasound beyond that point resulting in a shadow behind the echoreflective structure, which follows the ultrasound signal. The reverberations are artefacts caused by secondary false echoes of the same structure and are more common in strong echoreflectors such as calcium, stent or the guidewire. Finally, the blood speckles are spots that are moving with a characteristic pattern and are due to the reflection of the signal by the red blood cells (Nissen et al. 1998). From the above it is obvious that there is a variety of artefacts which renders the automated segmentation of the IVUS images a challenging process.

**MAIN FOCUS**

**Primitive IVUS Processing Methodologies**

The first IVUS processing methodology was developed by Rosenfiled et al. (1991) who stacked the acquired IVUS frames to form a cylinder – shaped object. This simplistic approach is still useful in