Guest Editorial
Introduction to the Special Section on Computer Vision for Intravascular and Intracardiac Imaging

THIS SPECIAL section of the IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE is devoted to advances in computational techniques in the field of intravascular and intracardiac imaging. Despite improvements in a number of noninvasive techniques, cardiac catheterization remains a key clinical tool for assessing the anatomy and physiology of the heart and its associated vasculature. A small catheter (usually a hollow plastic tube with 2–3 mm diameter) is inserted into a patient's peripheral artery or vein and advanced to the heart. Once properly positioned, it can be used for cross-sectional imaging through a transducer placed in the catheter, ablation of pathological tissue, pressure measurements, or injection of a contrast agent. Diagnostic cardiac catheterization helps in characterization of the extent and severity of cardiac and cardiovascular diseases, and thereby helps in planning for appropriate medical, surgical, or catheter-based treatment. While the majority of patients with coronary artery disease or valvular disease can be tracked with only clinical and noninvasive data, cardiac catheterization and angiographic procedures remain the preferred choice for the physicians for diagnostic or interventional purposes, or both. This special section focuses on the advances for computational methods based on computer vision and image processing principles for intravascular and intracardiac imaging and associated computer-aided diagnosis, treatment, and prognosis.

The motivation for this special section arose from the fact that although there is considerable activity in this relatively new field, there were not many forums or venues where the researchers could come together. Therefore, first, the Guest Editors of this issue organized a workshop at the Medical Image Computing and Computer Assisted Intervention (MICCAI) 2006, in Copenhagen, Denmark. This meeting brought together some pioneers in the field with keynote talks from Prof. Milan Sonka of the University of Iowa, and Dr. Stéphane Carlier of the Cardiovascular Research Foundation (now with Cordis Corporation, Belgium). With the keen interest and participation from the scientists in this community to the workshop, the Guest Editors wanted to carry this momentum to this issue.

Cardiac catheterization can be guided and imaged through various imaging modalities: X-ray, intravascular ultrasound (IVUS), magnetic resonance imaging (MRI), and optical coherence tomography (OCT), in which progressive improvements are poised to have dramatic impact on the diagnosis, analysis, modeling, and treatment of vascular diseases and cardiac disorders. A major disease of interest is atherosclerosis, which is characterized by a deposit of plaque in an arterial wall over time. Inflamed, active, and growing atherosclerotic plaques are believed to be "vulnerable" plaques. The disruption of such plaques is considered to be the most frequent cause of heart attack and sudden cardiac death. However, the mechanisms responsible for the sudden conversion of a rupture-prone plaque to a life threatening atherothrombotic lesion are not fully understood yet.

IVUS is a widely used clinical tool in the catheterization laboratory for guiding percutaneous interventions. Recent methods based on spectral analysis of the backscattered radiofrequency (RF) signal offer characterization of plaque into fibrotic/fibrofatty/lipid necrotic core/calcium. OCT is a newer intracoronary imaging modality that provides real-time very high-resolution tomographic visualization of coronary arteries (resolution $\sim$15–20 μm) [1]. Identification of plaque composition, particularly characterization of rupture-prone plaques, from these image modalities is an active research problem in the intravascular image analysis domain [2], [3].

Catheter-based X-ray angiography, which is radiography of blood vessels through the injection of an iodine-containing fluid into the arteries or veins followed by a subtraction image operation, is the current standard for diagnosis of coronary artery disease and in guiding cardiac and peripheral vascular interventions. Other common uses are stenosis quantification, detection of aneurysms, and dilations of the vessels through vascular wall segmentation or edge detection. It is also used to reconstruct a 3-D model of the artery from single-plane, biplane, or very recently rotational angiography to study hemodynamics, stress/strain distribution, and mechanical properties of the arterial wall. The latter application is preferably coupled with IVUS catheterization for an improved understanding of the arterial tissue properties [4], [5].

Catheter ablation involves the selective destruction of the cardiac tissue responsible for arrhythmias via percutaneously placed catheters. Recently, studies for use of late-contrast-enhanced MRI (CE-MRI) in such procedures enabled visualization of myocardial scar tissue that contains arrhythmia substrate. Delineation of scar tissue, which could be facilitated by myocardial segmentation, would be useful in clinical studies of myocardial scar and its impact on cardiac disorders.

Echocardiography is a diagnostic imaging technique that employs ultrasound to image organ anatomy. For contrast-enhanced ultrasound, gas-filled microbubbles are injected into the venous system to improve tissue and blood delineation (e.g., evaluating myocardial perfusion). The latest ultrasound systems now employ 3-D real-time imaging.

Computational and mathematical techniques designed to analyze intravascular images for anatomic modeling as for the 3-D reconstruction of the arterial wall anatomy from X-ray angiography and IVUS, visualization, arterial wall tissue classification particularly from IVUS and OCT, and the assessment of interventional procedures (X-ray and others), cardiac and intracardiac anatomic modeling for myocardium and left ventricle wall, and pathologic tissue (like scar tissue within) are therefore playing a role of increased importance and are currently receiving significant interest [1]–[17].

The Guest Editors invited papers presenting new techniques for any aspect of computational intravascular or intracardiac image analysis and processing. We opted to select a representative set of papers from among a number of very good submissions, which we hope will give readers a reasonable sense for some of the new and exciting research in this field. The research included in this issue covers a wide range of topics, from image-based frame gating of IVUS images, strain and shear analysis using elastograms for studying plaques, new computational methods for extraction of both inner and outer arterial walls from IVUS pullbacks, analysis of plaque characterization methods through feature extraction and appropriate statistical classifiers using IVUS RF data, myocardial and left ventricle segmentation from CE-MRI data in the presence of scar tissue for patients with atrial fibrillation, to 3-D IVUS transducer tracking from single-plane angiography for the purpose of 3-D arterial model reconstruction.

To give a more detailed introduction of the contents of this issue, Baldewsing *et al.* provides an automated method for reconstructing the elasticity distribution of heterogeneous atherosclerotic coronary plaques. This paper extends previous IVUS modulography work by including a novel divide-and-conquer computational strategy for reconstructing arbitrary plaques with a varied compositional structure. This approach is capable of estimating the total burden of dangerous soft thrombogenic material [8].

Maurice *et al.* presents for the first time, *in vivo* radial strain and shear along with tangential strain elastograms for both animal and human studies. The method relies on the Lagrangian speckle model estimator to estimate radial/axial as well as circumferential/lateral displacement fields, and shows much promise in characterizing atherosclerotic plaques and mural thrombi [9].

O'Malley *et al.* address the problem of eliminating motion artifacts in IVUS pullback sequences using image-based frame gating as an alternative to ECG gating. The computationally inexpensive frame gating method automatically chooses the fraction of the cycle that produces the most stable (in terms of interframe similarity) gated set of images [10].

In Jourdain *et al.*, the authors address the problem of correct geometric estimation of the 3-D model of the artery from a single angiogram. For this purpose, they present a method for IVUS transducer localization through a single-plane X-ray image sequence, given the pullback speed of the IVUS transducer as prior information as well as a rough estimate of the starting depth or mean depth of the trajectory of the transducer in the scanned artery using both full- and weak-perspective camera models for the X-ray system [11].

Katouzian *et al.* address the challenges of *in vivo* atherosclerotic plaque characterization in IVUS imaging, which is reflected by changes in spectral contents of the ultrasound RF signal. They analyzed a number of spectral features (e.g., spectral slope and intercept) that were used before and shown to be prone to variations of catheter and tissue spectral parameters. The authors made a rigorous attempt to address two important questions in tissue characterization: how to extract the *most informative* features; and which classification algorithm is *most appropriate* to the problem? [12].

Folkesson *et al.* present an automatic segmentation method for myocardium with scar tissue from contrast-enhanced MRI data for the final purpose of aiding the catheter ablation therapy in atrial fibrillation disorder. They incorporated a supervised learning in terms of a statistical classifier into a geodesic active region framework in order to particularly deal with irregular appearance due to scar tissue in the myocardium. A shape prior obtained from a shape particle filtering is also combined into the final segmentation for the epi- and endocardium with an additional coupling term for the two contours [13].

Unal *et al.* offer a novel learning-based method for segmentation of the inner and outer arterial walls from intravascular ultrasound images. Their method is based on shape and image intensity priors along with global image measurements. They also incorporate an anatomic feature detection step to account for calcifications and branch openings in IVUS pullbacks to further improve the quality of the arterial wall extraction, which will later be utilized in plaque analysis during the assessment of the atherosclerosis disease [14].

Van Soest *et al.* address the problem of correcting for image degradation due to nonuniform rotation distortion encountered in imaging modalities that use a mechanically rotated endoscopic probe. To that end, they present a new method to align individual lines in a sequence of images that accurately captures slow intraframe variations in rotational velocity of the probe [15].

Danilouchkine *et al.* present a method for quantitative assessment of the amount of vessel wall tissue motion due to catheter rotation. Their method is based on the scale-space optical flow algorithm with a feature-based weighting scheme and it shows reliability in prediction of catheter rotational motion up to 4° [16].

Roy *et al.* present a method for indexing echocardiograms for better content management. Specifically, the authors propose a hierarchical state-based model for representing an echo video, where the semantics of each video segment are captured using the characteristics of the objects depicted [17].

In summary, the papers from this special section provide the reader with representative samples of important advances in computational methods for intravascular and intracardiac image analysis. The major challenges for the future involve advanced computational modeling of vasculature and cardiovascular disease supported by imaging, fusion, and analysis of multimodality imaging, as well as innovative image-guided interventional

techniques for disease management and treatment. While better hardware is essential for these tasks, cutting-edge algorithms implemented on faster and more powerful computers will further improve the processing and interpretation of the imagery. Thus, we believe that the development of newer and more robust computational schemes for medical image processing is crucial in order to get the maximum benefit out of the latest imaging devices being introduced by the major original equipment manufacturers.

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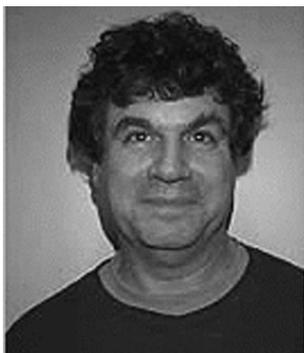
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