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Geometric modeling and motion analysis of the epicardial surface of the heart

Bernhard Quatember [a,*], Martin Mayr [a], Wolfgang Recheis [a], Stefanos Demertzis [b], Giampietro Allasia [c], Alessandra De Rossi [c], Roberto Cavoretto [c], Ezio Venturino [c]

[a] *Innsbruck Medical University (Radiology), Anichstrasse 35, 6020 Innsbruck, Austria*
[b] *Cardiocentro Ticino, Via Tesserete 48, 6900 Lugano, Switzerland*
[c] *Universita degli Studi di Torino (Matematica), Via Carlo Alberto 10, 10123 Torino, Italy*

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Abstract

Pathological processes cause abnormal regional motions of the heart. Regional wall motion analyses are important to evaluate the success of therapy, especially of cell therapy, since the recovery of the heart in cell therapy proceeds slowly and results in only small changes of ventricular wall motility. The usual ultrasound imaging of heart motion is too inaccurate to be considered as an appropriate method. MRI studies are more accurate, but insufficient to reliably detect small changes in regional ventricular wall motility. We thus aim at a more accurate method of motion analysis. Our approach is based on two imaging modalities, viz. cardiac CT and biplane cineangiography. The epicardial surface represented in the CT data set at the end of the diastole is registered to the three-dimensionally reconstructed epicardial artery tree from the angiograms in end-diastolic position. The motion tracking procedures are carried out by applying thin-plate spline transformations between the epicardial artery trees belonging to consecutive frames of our cineangiographic imagery.

Keywords: Cardiac motion tracking; Surface mesh generation; Registration; Thin-plate spline transformation; Radial basis function

1. Introduction

In all industrialised countries, coronary artery disease is one of the most serious public health problems. At present, the quality of medical care in the field of heart diseases is at a higher level than ever before. Cardiac images are taken from about four percent of the population every year. A large proportion of these individuals who undergo these examinations are suspected of having coronary artery disease. Thanks to the widespread availability of multi-slice CT scanners [12,13,18], it has become usual clinical practice to first refer these individuals to cardiac CT [10,12]. If the presence of coronary artery disease cannot be excluded with this less invasive imaging modality, conventional X-ray angiograms, which are significantly more invasive, are indicated as a second line of investigation. Coronary angiography is decisive for the final diagnosis and the planning of therapy [12]. Thus, in many cases images of both modalities, viz. three-dimensional CT data sets and biplane angiograms are at the disposal of the cardiologist. In

* Corresponding author.
E-mail address: Bernhard.Quatember@uibk.ac.at (B. Quatember).

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current clinical practice, the routine analyses of this multimodal imagery focus mainly on the patency of the coronary (epicardial) arteries, in particular, the assessment of the stenoses and on investigations of the calcifications within the arterial walls, especially in regions of haemodynamically relevant stenoses [10,12,16,18].

The end-effector of coronary heart disease is the heart muscle. In particular, pathological processes within the myocardium manifest themselves in abnormal (regional) motions of the heart. Myocardial hypoperfusion can induce hibernation, hypo-, a- or dyskinesia of the affected coronary territory. Motion analyses will thus enable cardiologists to delve into greater detail in their diagnoses of coronary artery disease [2,3]. At present, however, heart wall motion abnormalities are usually inaccurately detected, on the basis of ultrasound images [2]. More accurate motion studies based on CT imagery and biplane angiograms are only occasionally carried out. The reason why such investigations are not more frequently undertaken may be the required application of computationally extremely expensive algorithms. However, it might now become possible to eliminate such restrictions, since high-performance computing facilities are already available at a reasonable price.

Heart motion analyses are not only important for the diagnosis of coronary artery disease, they are rather instrumental in assessing the success of revascularisation and other measures to repair the damaged heart. This is particularly true in the case of examinations of the improvement of ventricular function achieved by the regeneration of hibernating cardiac tissue after successful reperfusion and the repair of infarcted myocardium by means of stem cell therapy [1,9,11,18]. Regional myocardial contractility recovers slowly and gradually [1]. For this reason, cardiologists need accurate information about even small changes in the regional wall motion of the heart to reliably assess the success of the therapy.

During the past decades, much effort has been devoted to achieving an improved understanding of the contractions of the heart. Numerous methods have been developed and applied to capture specific data from medical images which are then used to describe the motion of the heart.

In the early stage of development, methods for the three-dimensional motion tracking of the coronary arteries based on biplane cineangiograms were conceived [23,26,27]. Thereafter, methods for motion analyses of the heart (more specifically, of the left ventricle) with MRI tagging imaging became the focus of interest. With the advent of EBCT scanners and in particular of multislice CT systems, motion analyses involving these imaging modalities have become feasible. However, the limited spatial resolution of EBCT and the insufficient temporal resolution of ECG-gated multislice CT do not yet allow cardiologists in clinical settings to carry out reliable studies of the motion of the heart.

In the following, we will describe the development of a method for performing patient-specific motion analyses of the epicardial surface of the left ventricle for clinical use. It is based on already existing imagery (biplane cineangiograms and three-dimensional CT data sets). A specific goal of our research is to make the method applicable for the detection and investigation of even small changes in the regional motility of the myocardium.

After a brief overview of the state of the art in the next section, we will describe our approach in Section 3. This description of the main concepts and the justification for utilizing them is followed in Section 4 by a demonstration of the clinical applicability of our approach and by some remarks on software implementation details. Our main results are presented in Section 5. In Section 6, we deal with specific motion analysis and visualisation aspects.

2. Objectives and contribution beyond the state of the art

We will deal with the development of methods and software modules to acquire an accurate knowledge of the regional variations of the motion of the epicardial surface of the left ventricle. We confined ourselves to the motility of the epicardial surface of the left ventricle and did not consider the inner surface of the ventricle. We have to bear in mind that the epicardial surface is mainly convex and can thus appropriately be described. In contrast, the inner ventricular surface contains immured trabecular structures and papillary muscles. Thus, markedly convex regions of this inner surface will alternate with concave regions which makes it difficult to acquire its geometry and in particular to accurately describe regional motion patterns.

2.1. Central objectives

We aim at a method and software system to investigate and quantitatively assess regional variations of the motion of the epicardial surface of the left ventricle; our method is based on the medical imagery of a patient, viz. cardiac CT and biplane cineangiography. In particular, we aim at: