# SPEQLE (Software Package for Echocardiographic Quantification LEuven) an Integrated Approach to Ultrasound-Based Cardiac Deformation Quantification

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## Abstract

*A software package, called SPEQLE, was developed to integrate the offline analysis of ultrasound based deformation imaging build on three integrated components (data organization, data extraction, timing/parameter extraction). At acquisition, digital DMI/SRI data sets are stored in a manufacturer-dependent data format. The data-organizing component converts this format into a standardized format and adds these data to the investigation of a patient defined within the study population of a project on a data server. The data-extraction component takes care of extracting velocity and strain rate traces based on tracking of an anatomical region of the myocardium through the 2D echo image. It provides an environment to manually track an anatomical region of the myocardium. The timing/parameter extraction component allows to define the timing of cardiac events based on the simultaneously presentation of different synchronous traces such as blood pool Doppler, M-mode images, pressure traces... Finally, this component takes care of user-defined parameter extraction (various values quantifying velocity, displacement, strain and strain-rate during the cardiac periods), that are stored into the data structure. This integrated approach helps in standardizing and speeding up ultrasound deformation research.*

## 1. Introduction

Ultrasonic imaging is the non-invasive clinical imaging modality of choice for diagnosing heart disease. Two-dimensional grayscale imaging (for a review see [1]) provide a relatively cheap, fast, bed-side method to study the morphology and wall motion of the heart. The non-invasive quantification of regional myocardial function (i.e. performance) is an important goal in clinical cardiology. Roughly, the cardiac cycle is subdivided into two main intervals: systole and diastole. Accordingly myocardial function has been subdivided into performance associated to ejecting blood from the ventricles (systolic function) and performance associated with filling of the ventricles (diastolic function). Regional myocardial deformation is intricately related to myocardial function and can be assessed non-invasively by ultrasound.

To this end, Doppler Myocardial Imaging (DMI) and Strain Rate Imaging (SRI) [2] have been introduced as new echocardiographic modalities. Based on processing myocardial velocity estimates, one-dimensional myocardial deformation, by integrating the spatial velocity gradient (strain rate) along the ultrasound beam, of several wall segments can be quantified during the cardiac cycle, i.e. at least one component of the deformation tensor can be fully quantified for each myocardial segment [3].

However, parameter extraction from DMI/SRI data sets most often requires a significant amount of post-processing especially when derived parameters such as displacement and strain are required. Therefore SPEQLE has been developed to integrate the processing chain in experimental and clinical ultrasound-based cardiac deformation research.

## 2. Data flow in ultrasound deformation research

The approaches to the organization of echocardiographic measurements in clinical/experimental research and clinical practice is quite different. In both cases we want to investigate a set of quantitive parameters. However, in research we want to compare groups of patients and understand pathophysiology and/or treatment. In clinical practice we want to investigate the individual patient and compare with normal and previous values to perform diagnosis and follow-up. Therefore, for research we want

interesting information as possible for complete groups of patients to understand generic pathophysiology. In the clinic, we want to make a fast, reliable conclusion based on 'just enough' information required for clinically relevant conclusions in the individual patient. Research requires off-line analysis, while in the clinic on-line analysis is preferred.

Myocardial velocity information can be obtained by storing the velocity data sets as calculated by the ultrasound scanner in a digital format or by staoring raw RF data sets and calculating the velocities off-line. During an ultrasound examinitation, myocardial velocity data of as much wall segments as possible are acquired from the different echo slices. Additional datasets are aquired for timing purposes, i.e. grayscale M-modes at the level of the valves or intravalvular pulsed wave Doppler traces showing the onset and end f flow through the valves, to determine the timing of valve openings and closures. From the velocity data sets, strain rate is estimated by applying a spatial gradient operator on the velocity estimates. The length over which this gradient is calculated, is taken to be 5 mm or radial data sets and 10 mm for longitudinal ones. These lengths have to be adjusted to keep the region of interest inside the myocardium to avoid artefacts from incorporating blood velocities. As the operation of numerical gradients is uasually very noise sensitive, the velocity data sets are usually smoothed before applying a gradient operator. We apply a mean filter on the velocity datsets with a mask of 5x3 pixels in the axial and lateral directions for radial data sets and a mask of 5x1 pixels for longitudinal data sets. Additional noise reduction is obtained by averaging the extracted velocity/displacement and strain rate/strain traces over 3 consecutive cardiac cycles.

Since the heart is moving within the ultrasound image during the cardiac cycle, tracking of the myocardium is important to make sure that the extracted velocity(and derived) traces represent the same myocardial segemnt over he whole cardac cycle. At present, this tracking has to be done manually by moving the region of interest, which is a tideous and the most time-consuming task within the processing chain.

After the extraction of velocity and strain rate traces of the myocardial wall segements, the timing of the cardiac cycle has to be performed. In order to correlate measured velocity/strain rate and strain values to specific mechanical phases of the cardiac cycle, accurate timing of these mechanical events is required. Herefore, information on opening and closing of the valves is necessary. Moreover valve closures generally generate specific peaks in the velocity or strain rate curves. Simultaneously acquired ventricular pressure traces can also be used for timing. The cardiac cycle is divided into the following events: (1) the period between the onset of the QRS complex on the ECG mechanical coupling (EMC) phase. This phase is followed by the isovolumetric contraction (IVC) which end when the aortic valve opens. Ejection (Ejec) follows and ends when the aortic valve closes. It is followed by the isovolumetric elaxation phase (IVR) that ends by mitral valve opening. Ventricular filling then exists out of the early filling phase (E) and an atrial or late filling phase (A) associated with atrial contraction. The onset of atrial filling is defined by the the onset of the P-wave on the ECG.

The precise definition of the different mechanical cardiac events requires an accurate time alignment of the velocity/strain rate/strain traces with the M-mode/pulsed wave Doppler/pressure infromation. Differnet acquisitions within the same patient are at present linear interpolated through the ECG, which requires more or less constant heart rates.

Finally after the anatomical tracking to abtain temporal information on velocity/strain rate and strain, parameters can be extracted from these curves during the different cardiac phases, on the basis of the tming defined above. Parameters that have been investigated most extensively are: peak velocity/strain rate and strain during ejection and timing of these values with respect to the QRS complex together with peak values and their timing during early and late filling. The investigation of isovolumetric parameters requires high temporal resolution to resolve the fast events occuring in these phases.

## 3. Software package

All the post-processing steps described above have been implemented in an integrated software package. The complete package was developed in Matlab (MathWorks Inc.) except for some numerically intensive operations such as scanconvertion of the 2D echo images, which have been implemented in C and linked to Matlab through the Matlab MEX Interface. Due to this development in matlab the package is highly platform independent. The package is freely available for research purposes. This software has been used in our laboratory by 10 reseachers managing around 20 projects.

The software package essentially consists of three linked components. *1. The data-organizing component* (Figure 1) of SPEQLE takes care of organizing the ultrasound data. Data is currently organized in project groups (e.g. 'experimental ultrasound', 'clinical ultrasound', 'pediatric ultrasound', ...). A project defines a complete study population, which can be divided in subgroups (e.g. normal subjects, mild ischemia, severe ischemia). The post-processing parameters (such as averaging) are set at project level, to ensure standardized processing of the data inside one project. When patients are added to a project

scanner is converted to standardized datasets (stored as Matlab mat-files). Velocity datasets are either retrieved from the calculated velocity datasets on the scanner or calculated off-line frow raw RF data. After the conversion, the patient datasets are added to a patient inside a project (subgroup). All data sets are renamed according to the

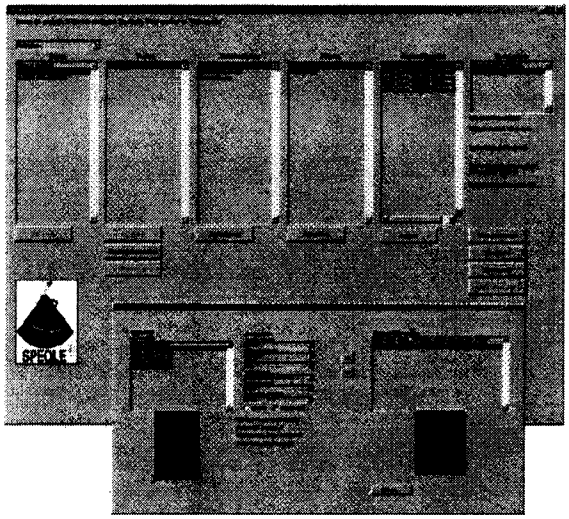


Figure 1. The data-organizing component.

guidelines of the American Heart Association [4] for ventricular segmentation and their acquisition (modality: tissue/blood; mode: grayscale, M-mode, pulsed Doppler,...; echo view: parasternal long axis, apical four chamber, ...). This component also manages several analyses performed by the same or other users on one dataset.

2. *The data-extraction component* (Figure 2) takes care of extracting velocity and strain rate traces. It provides an environment to manually track an anatomical region of the myocardium. The tracking is done currently on the basis of two orthogonal anatomical M-modes, which can be further adjusted, by moving the region of interest in the 2D echo image. Velocity/strain rate and strain traces are shown simultaneously and updated continuously during the tracking. This enables the user to perform quality control of the extracted traces, avoiding image artefacts. During the tracking a mask is shown on the image to mark all the pixels that are taken into account in the calculation of the traces (including the averaging mask). The position of the region of interest together with the post-processing parameters used is saved with the analysis and can be recalled later. Moreover, it provides the user with tools to represent his data sets in different ways such as anatomical M-mode, curved M-mode,... . This component also takes care of the introduction of additional physiological data, such as left-ventricular pressure data recorded simultaneously during

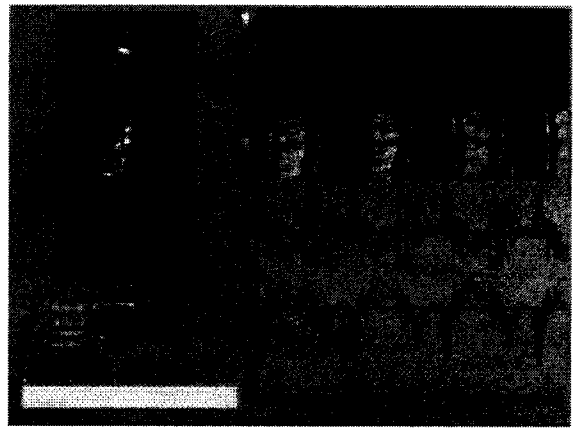

Figure 2. The data-extraction component.

3. *The timing/parameter extraction component* (Figure 3) allows to define the timing of cardiac events (e.g. valve closures) in order to divide the cycle into relevant periods (e.g. ejection, filling, ...). The different mechanical events of the cardiac cycle are timed based on the simultaneously presentation of different synchronous traces such as blood pool Doppler, M-mode images, pressure traces... Figure 3 shows an nexample of the timing of the mitral valve closure and opening. The top-image shows an anatomical M-mode at the level of the mitral valve leaflets clearly identifying openeing and closure of the valve, while the second image is a pulsed wave Doppler recording of the bloodflow through the mitral valve enabling the identification of the valve opening/closure on the basis of the onset and end of the flow. The simultaneous display of these traces makes it possible to do a further verification of the acquired timing signals.

Finally, this component takes care of user-defined parameter extraction (various values quantifying velocity, displacement, strain and strain-rate during the cardiac periods), that are stored into the data structure. At each step in the chain, processing parameters are saved with the analysis, allowing for re-entering the analysis chain to double check aberrant findings.

## 4. Conclusions

SPEQLE is an open-source software package providing an integrated offline approach to ultrasound based cardiac deformation imaging. It offers manufacturer-independent, documented, controlled and editable parameter extraction in a project oriented structure, features that are indispensable in a research environment. Therefore, it contributes to speeding up and standardizing DMI/SRI research.

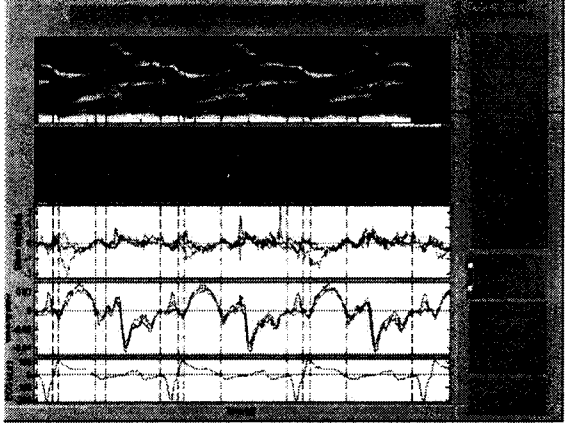

Figure 3. The timing/parameter-extraction component.

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